Investigating the development of knowledge using computational methods

Lisa Pearl

University of California, Irvine

lpearl@uci.edu

Computation of Language Laboratory

UC Irvine

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Johns Hopkins University

A current major issue facing education

Many children who are left behind with respect to early childhood learning experiences are put at a disadvantage for the rest of their education.

Designing intervention programs

One way to help these children is to design effective pre-school intervention programs that can stimulate their learning.

But how do we know what specific aspects of their learning experience to target?

Modern solutions to designing effective interventions

Interdisciplinary partnership between cognitive scientists and educators to

(1) identify the components of the learning experience that lead to typical learning vs. delayed learning

(2) determine how to enrich the learning experience to specifically benefit these components

Insights from some children to help other children

If we understand how learning proceeds for typically developing children who have an enriched learning environment, we can figure out how to trigger that learning process for other children.

Learning as ongoing mental computation

Learning as ongoing mental computation

Learning = given the available input,

You can touch them

Input

Do you see five of them?

Learning as ongoing mental computation

Learning = given the available input, information processing done by human minds

You can touch them

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Mental computation

Learning as ongoing mental computation

Learning = given the available input, information processing done by human minds to build a system of knowledge

You can touch them

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Do you see five of them?

VERB

see *touch*

abstraction & generalization

5

Mental computation

Learning as ongoing mental computation

Learning = given the available input, information processing done by human minds to build a system of knowledge whose output we observe

You can touch them

Input

Do you see five of them?

VERB

see *touch*

abstraction & generalization

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Mental computation

Output

I see five!

Investigating learning

Many different questions about this mental computation

Investigating learning

Many different questions about this mental computation

What learning strategies comprise it?

(Language: Phillips & Pearl in prep., Phillips & Pearl 2012, Pearl et al. 2011, Pearl et al. 2010)

Investigating learning

Many different questions about this mental computation

What learning strategies comprise it?

What learning biases do children need to succeed at it?

(Language: Pearl & Mis in rev., Pearl & Sprouse forthcoming, Pearl & Sprouse 2013, Pearl & Mis 2011, Pearl & Lidz 2009, Pearl 2008, Pearl & Weinberg 2007)

Investigating learning

Many different questions about this mental computation

What learning strategies comprise it?

What learning biases do children need to succeed at it?

What knowledge representations can be easily learned using it?

(Language: Pearl et al. in prep., Pearl 2011, Pearl 2009)

Investigating learning

Many different questions about this mental computation

What learning strategies comprise it?

What learning biases do children need to succeed at it?

What knowledge representations can be easily learned using it?

When do children learn different aspects of knowledge using it, and what data are available to them to do so?

(Language: Pearl & Braunwald in prep., Caponigro, Pearl et al. 2012, Caponigro, Pearl et al. 2011)

Methods of empirical investigation

Methods of empirical investigation

Theoretical methods:

What knowledge is (and what children have to learn)

LOOK at the KItties

look
at
the kitties

VERB

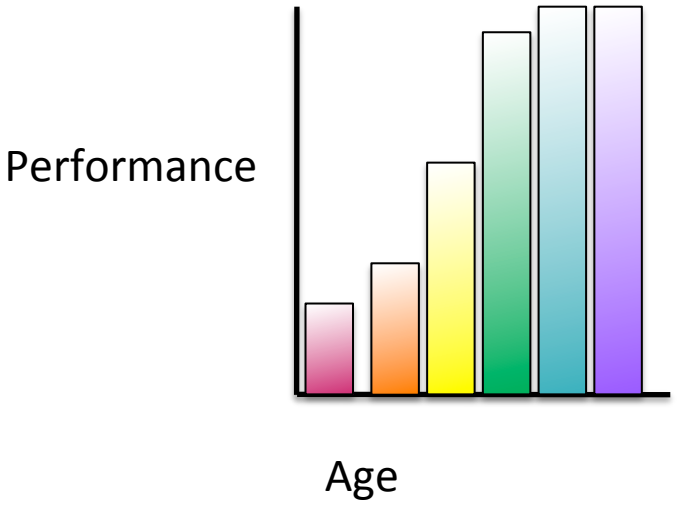
see *look at*

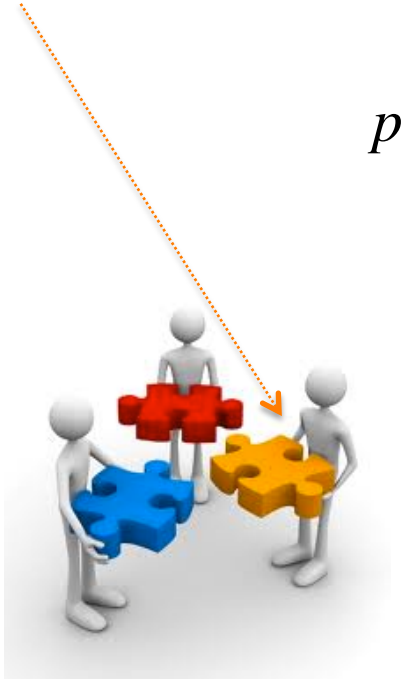
5

Methods of empirical investigation

Experimental methods:

When knowledge is acquired, what the **input** looks like, & plausible capabilities underlying **how** learning works

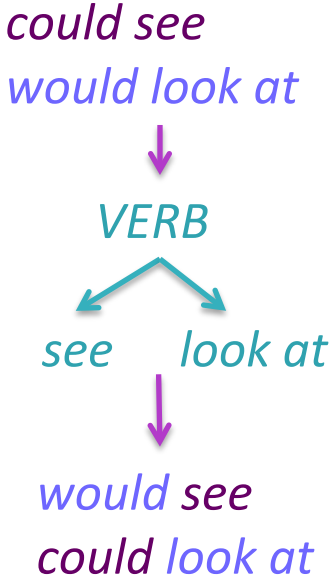


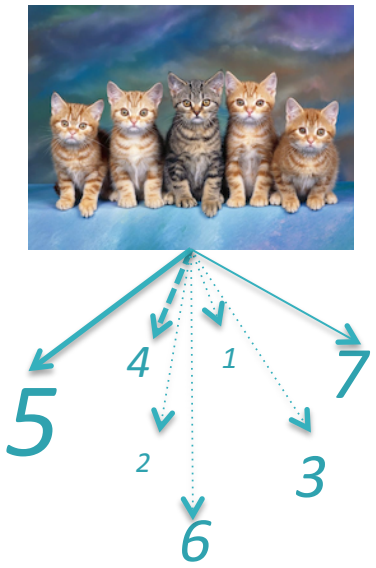


$$p(kitty \mid \text{  }) \propto p(\text{  } \mid kitty)\, p(kitty)$$

Methods of empirical investigation

Computational methods:
Strategies for **how** children acquire knowledge,
sophisticated **quantitative analysis** of children's input & output





Today's Plan

Using computational methods to look at one question about children's learning and discussing connections to education

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When does the child attain a certain level of knowledge?
Connections: literacy development

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Identifying factors that underlie the observable output:
What signifies atypical development, which may require intervention?
Connections: math readiness

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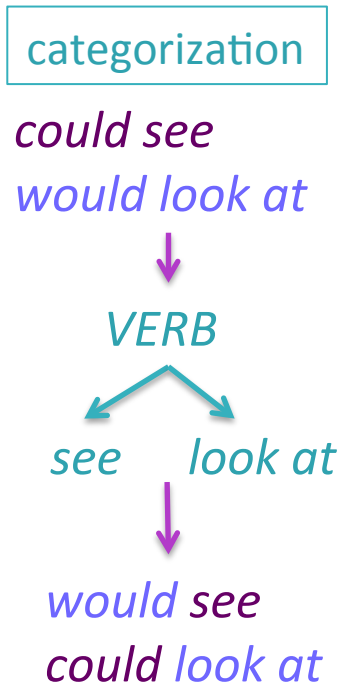

Language & Literacy

Language learning: Developing linguistic knowledge

→ phonemes, words, grammatical categories, phrases, …

One important part of this process:

Generalization = a more abstract unit encompasses a group of individual items.

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I love my ___.

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Noun

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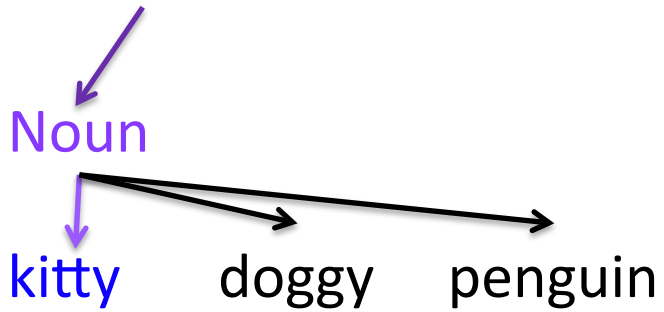

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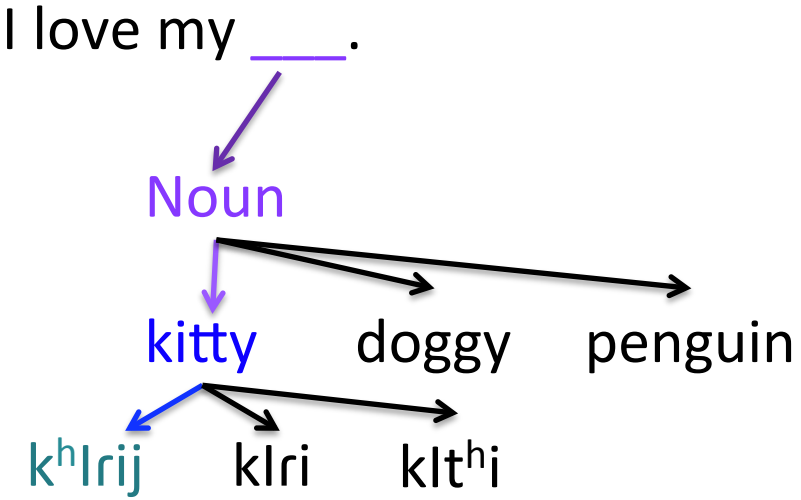

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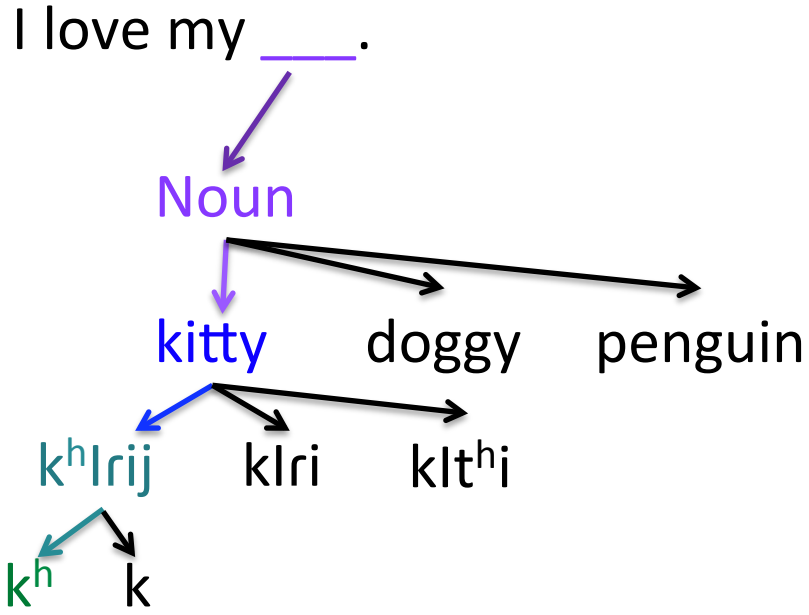

Language & Literacy

Spoken language knowledge: a prerequisite for literacy

Part of literacy: A mapping process

unconscious knowledge about spoken language

explicit symbolic representation of written language

/kIri/

kitty

Similar words: doggy, penguin

“kitty” is a noun

Language & Literacy

One part of literacy:

vocabulary development & reading comprehension

Current project with some ties to this process:

Investigating the development of grammatical category knowledge

kitty = noun

Grammatical categories

How does this relate exactly?

Grammatical category = the way a word behaves in combination with other words

If you know this: **kitty** = noun

You also know that all these are fine:

"**My kitty** is cute."

"I love **that kitty**."

"The little tabby kitty is particularly adorable."

"I gave some fish **to the kitty**.

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If you know how a word behaves, you know what other words behave like it, which allows you to transfer knowledge across words.

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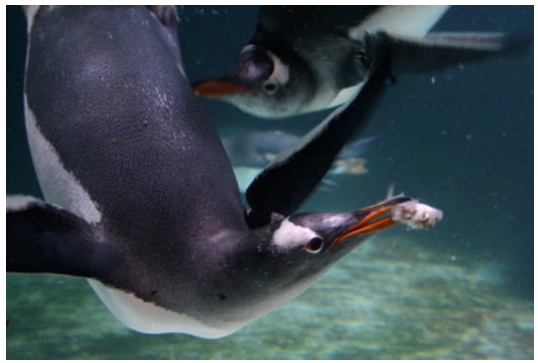

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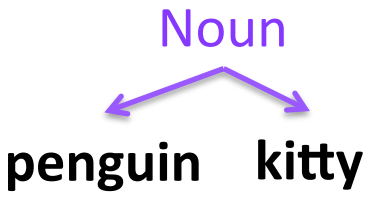

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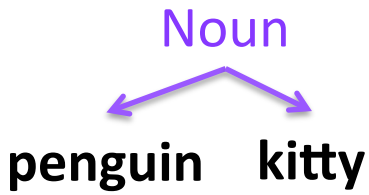

Therefore:

Those two kitties are eating fish.

Grammatical categories
for vocabulary development & reading comprehension

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If you know how words behave, this can help you learn new words, based on how the new word combines with other words.

[**Syntactic bootstrapping, in addition to semantic cues**]

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That **feline** is playing with the dog again.

Grammatical categories for vocabulary development & reading comprehension

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[**Syntactic bootstrapping, in addition to semantic cues**]

That **feline** is playing with the dog again.

That _____ is

↓

Noun

↓

entity

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[**Syntactic bootstrapping, in addition to semantic cues**]

That **feline** is playing with the dog again.

That ____ is related to *playing, dog*

↓

Noun

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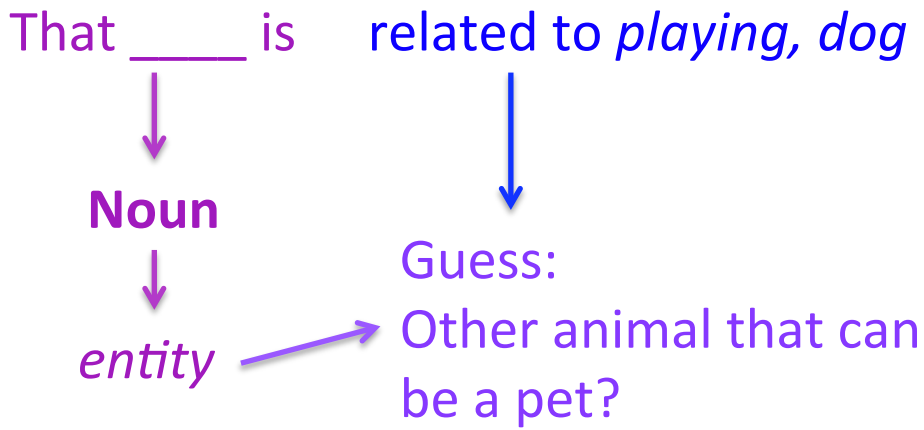

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That **feline** is playing with the dog again.

That ____ is → **Noun** → *entity*

related to *playing, dog* → Guess: Other animal that can be a pet?

Assessing knowledge of grammatical categories

Grammatical category = a group of words that behaves the same way

Very specific

Share many syntactic & semantic properties

Very general

Share a few core syntactic & semantic properties

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Verbs of communication
whisper, shout, say, mumble, tell, …

If you know "derb" is part of this category, you know this is probably okay:

Jack *derbed* the name to Lily.

Assessing knowledge of grammatical categories

Grammatical category = a group of words that behaves the same way

Very specific

Share many syntactic & semantic properties

Very general

Share a few core syntactic & semantic properties

Verbs

whisper, hug, think, give, breathe, …

If you know "derb" is part of this category, you know these are probably okay:

…could *derb*…
…might *derb*…
…will *derb*….

Assessing knowledge of grammatical categories

When do children first develop knowledge of the abstract category of “verb”?

Very specific

Share many syntactic & semantic properties

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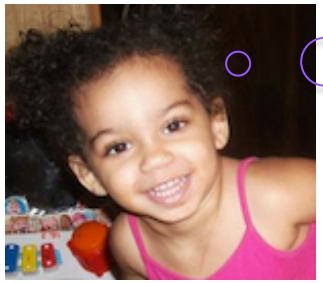
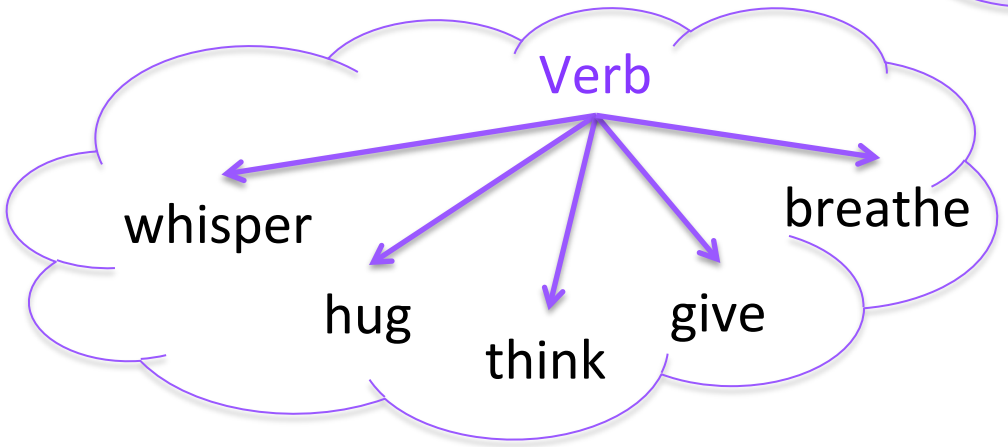
Share a few core syntactic & semantic properties





Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How can we tell?

One indicator:

Knowledge about how one word combines with other words is transferred within the category.

…could think…

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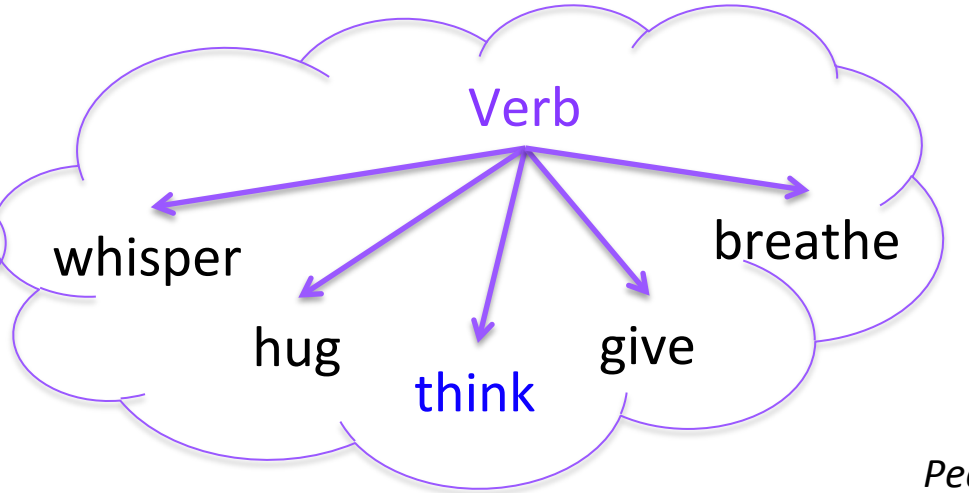

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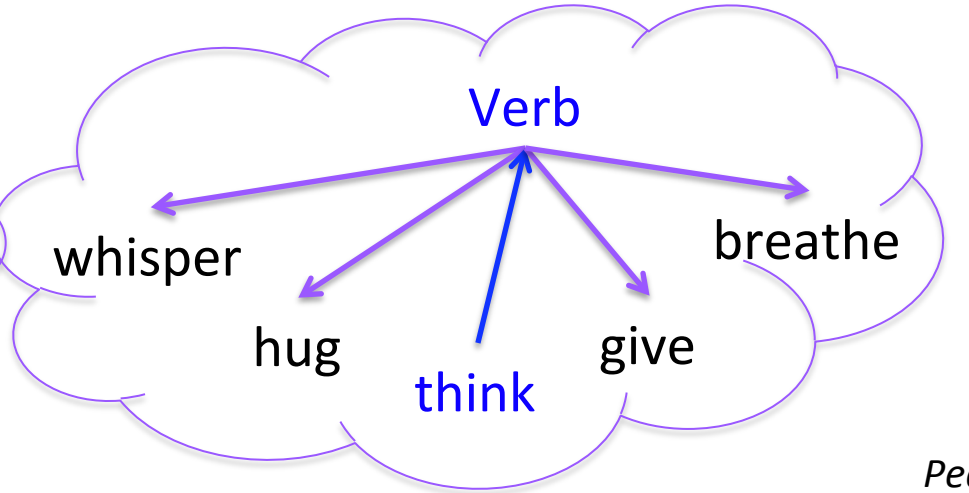

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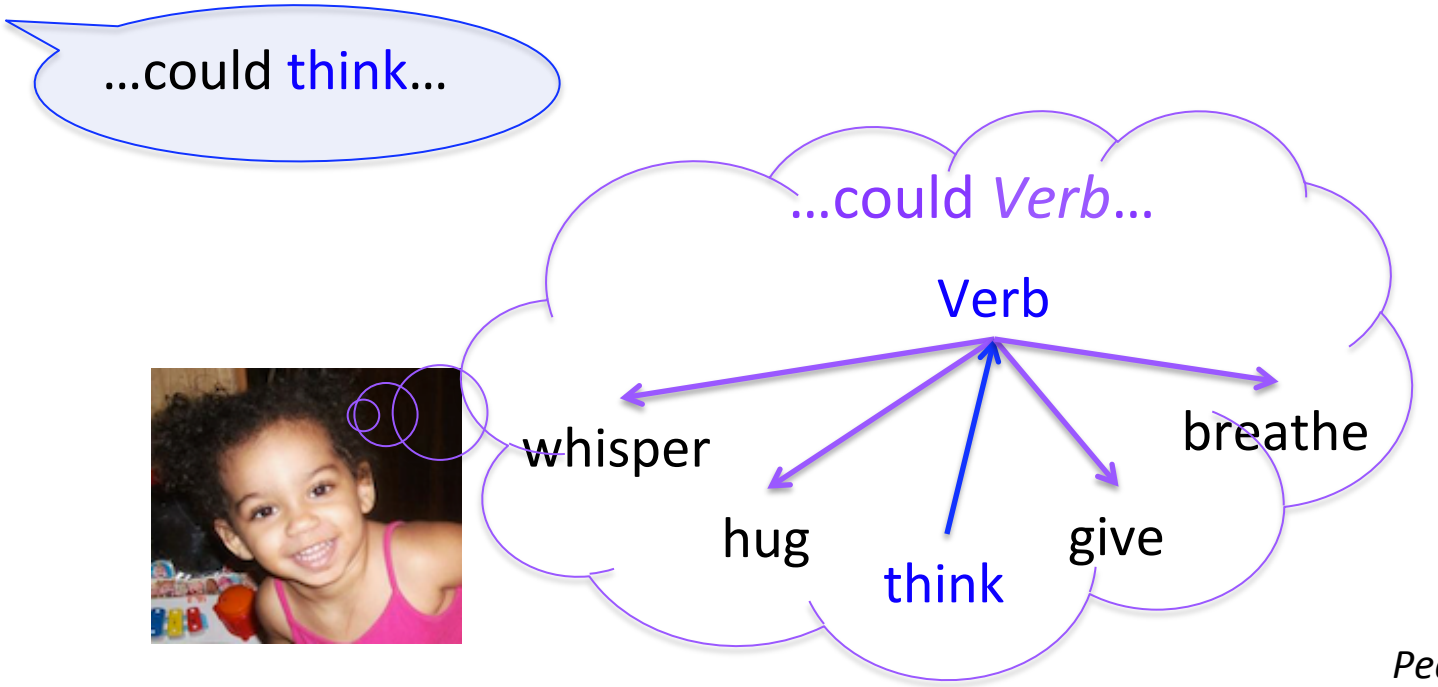

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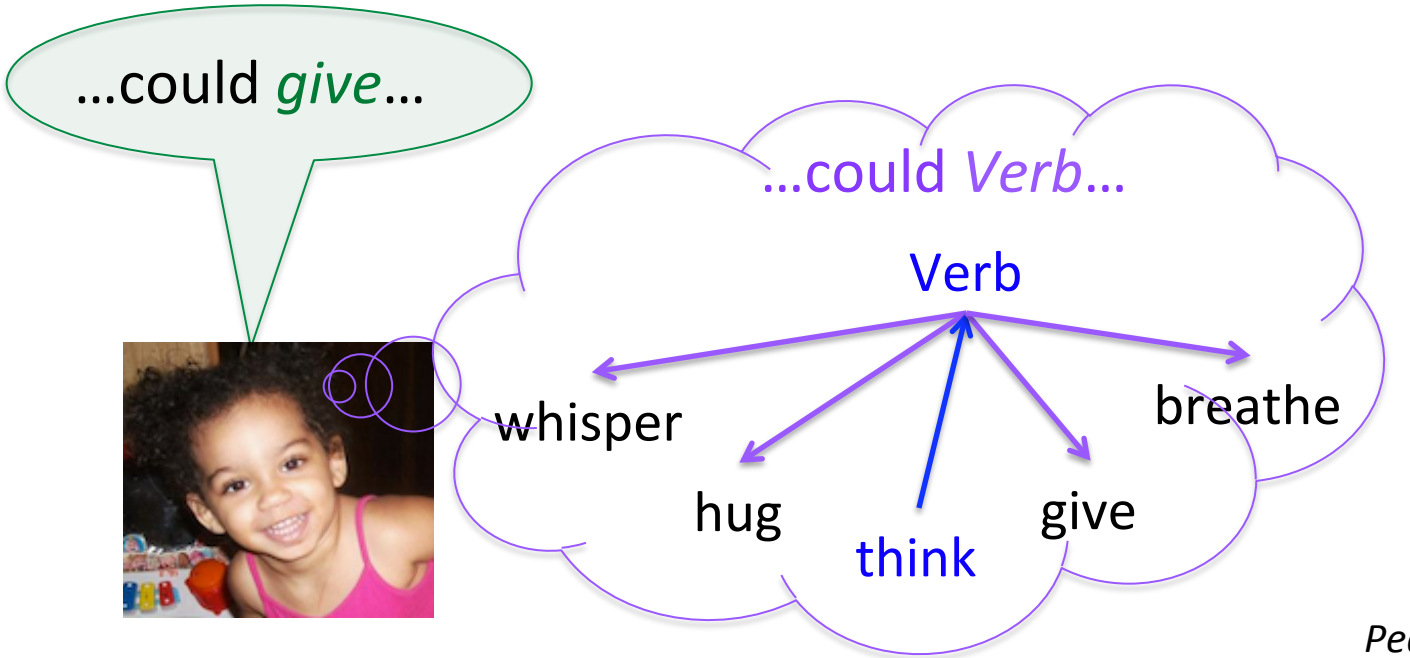

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Assessing knowledge of grammatical categories

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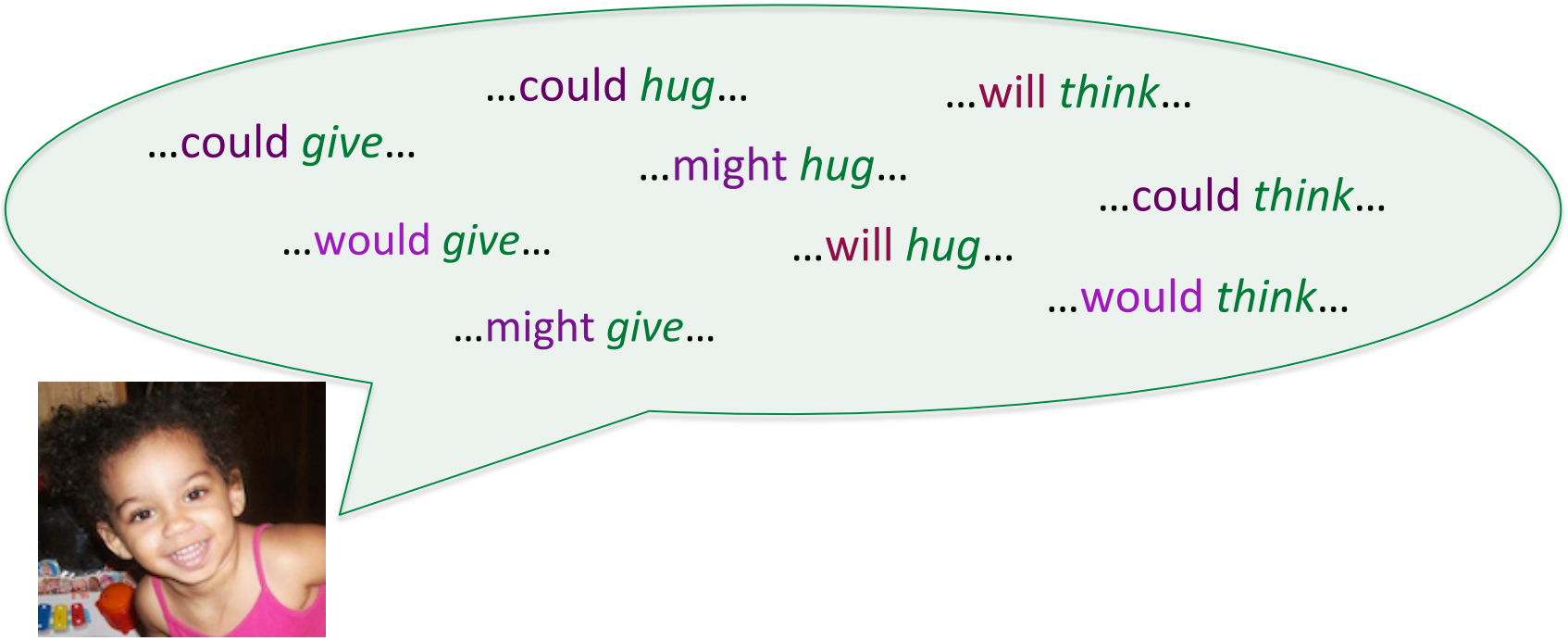
One indicator:

This causes the child to combine words of the same category with similar words, so that there's overlap in usage within a category.



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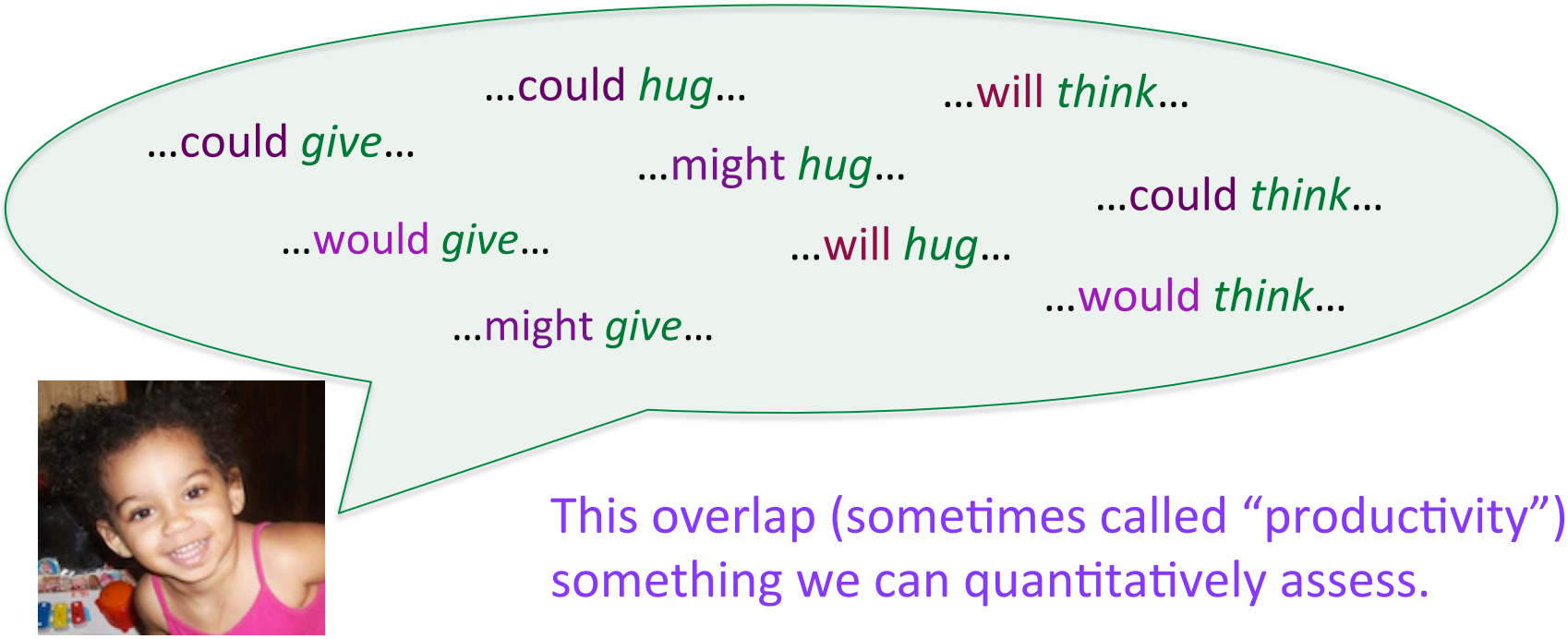


This overlap (sometimes called "productivity") is something we can quantitatively assess.

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

When does this kind of grammatical category knowledge typically develop?

Some evidence exists that it may already be in place around the age of two (Valian 1986), but some evidence also exists that it may appear significantly later than that (Tomasello 1992, Pine & Lieven 1997)




Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

Focus: Development of the category Verb

Data:

Longitudinal data from a typically developing child (Laura) in naturalistic contexts

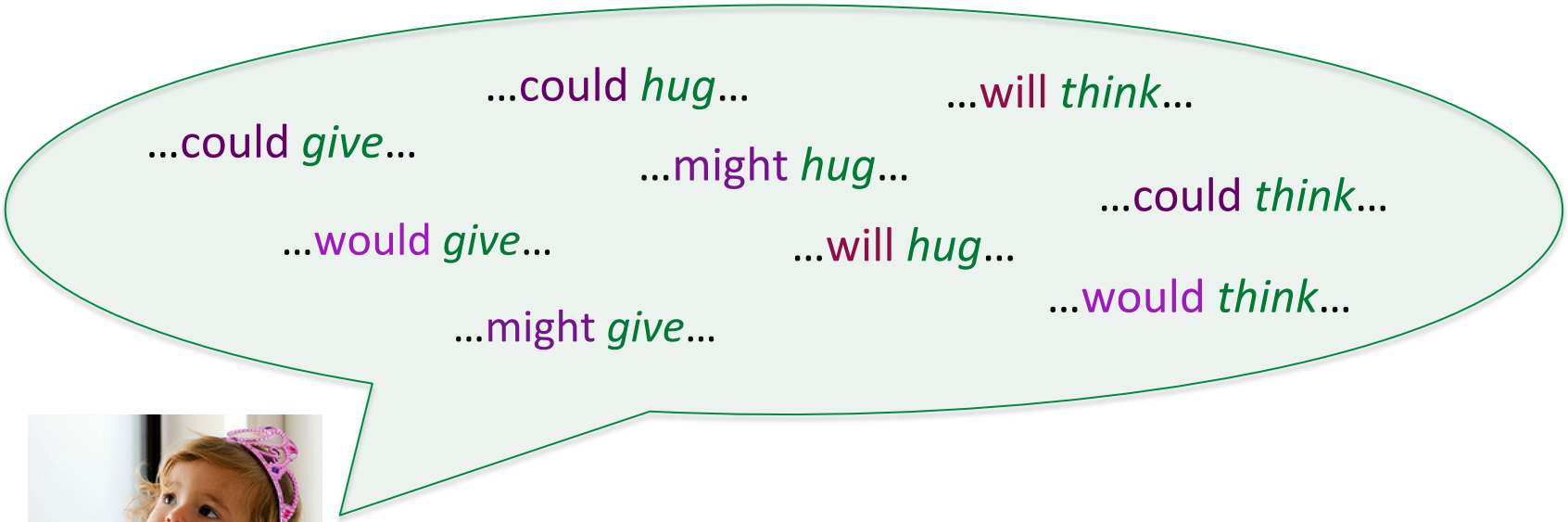
[Braunwald-Max Planck corpus from CHILDES database + hand-written diary data kept by Braunwald, 20- to 24-month subsection]

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

For example, should we expect every verb to combine with every auxiliary?



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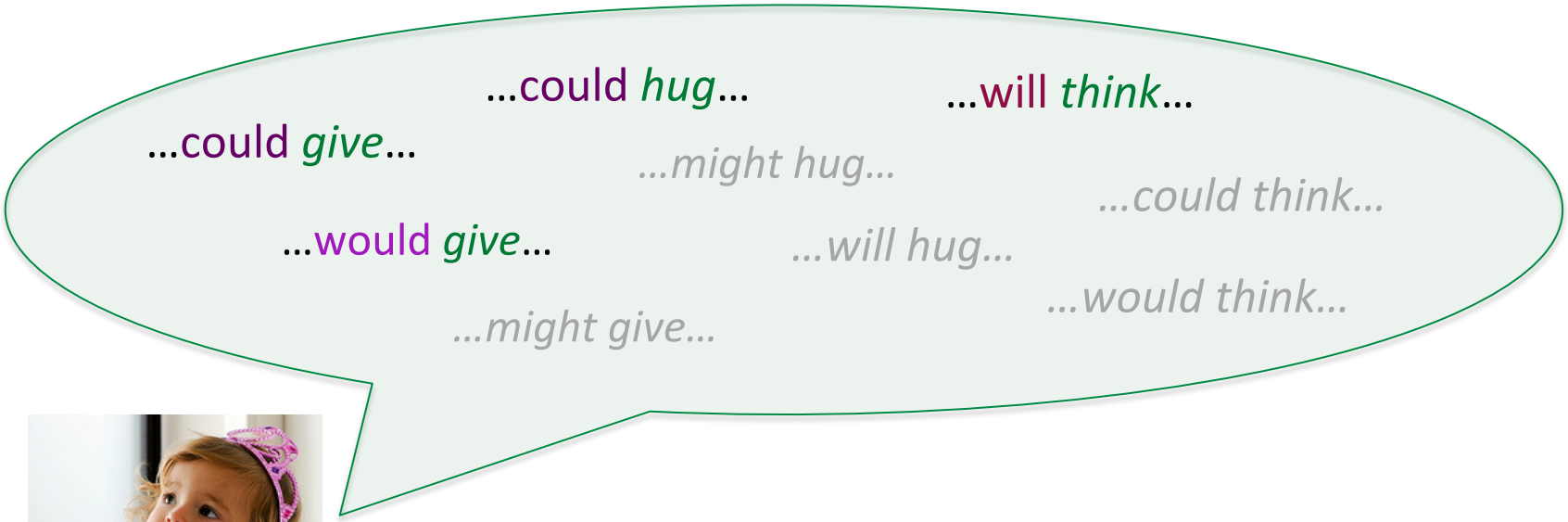


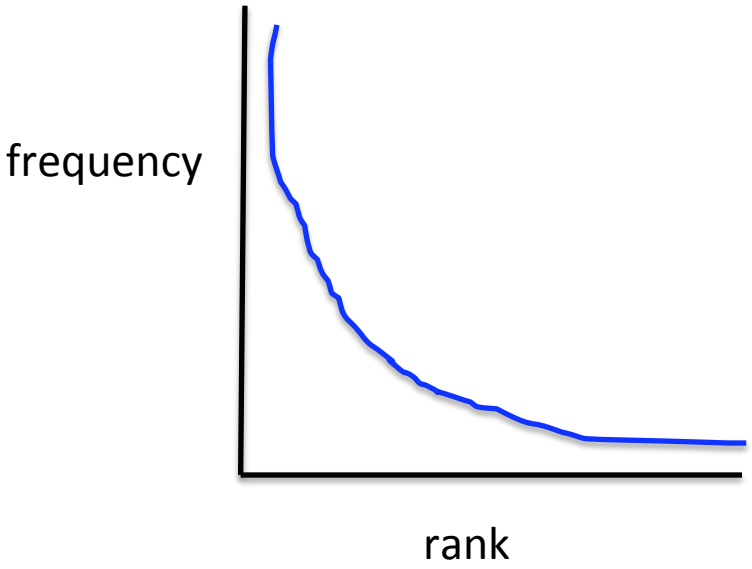
Probably not – remember, these are naturalistic outputs. We don't say everything we know when we speak – we say things to communicate our intended meaning at the time.

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

In fact, it turns out naturalistic linguistic output shows power-law behavior (a Zipfian distribution)...



verb	freq	rank
get	101	1
go	100	2
…		
feel	8	58
…		
dream	1	251
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Pearl & Braunwald in prep.

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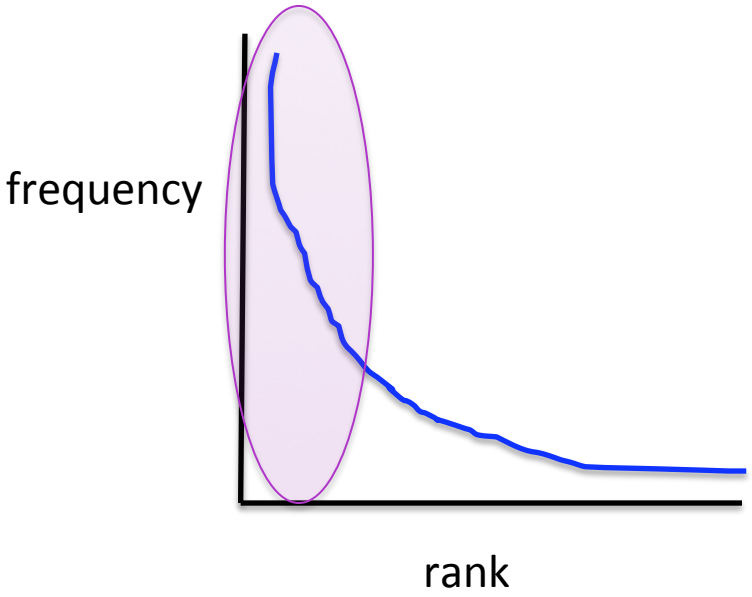

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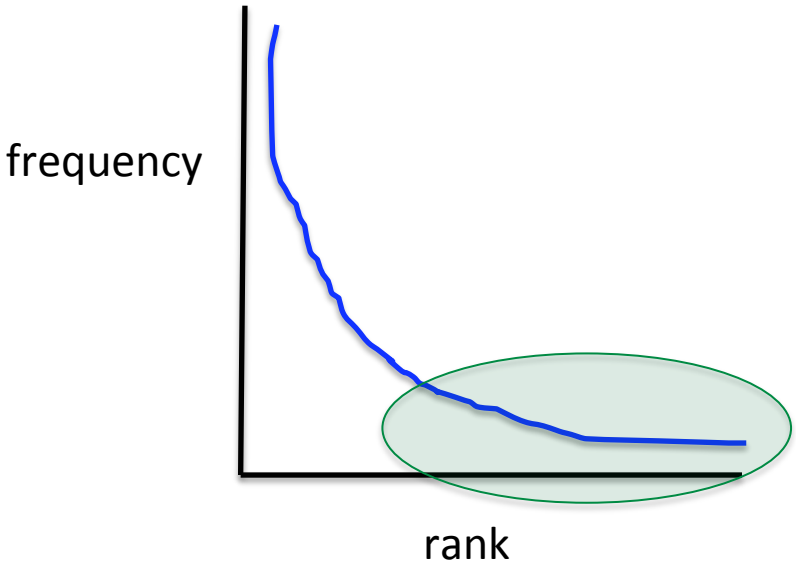

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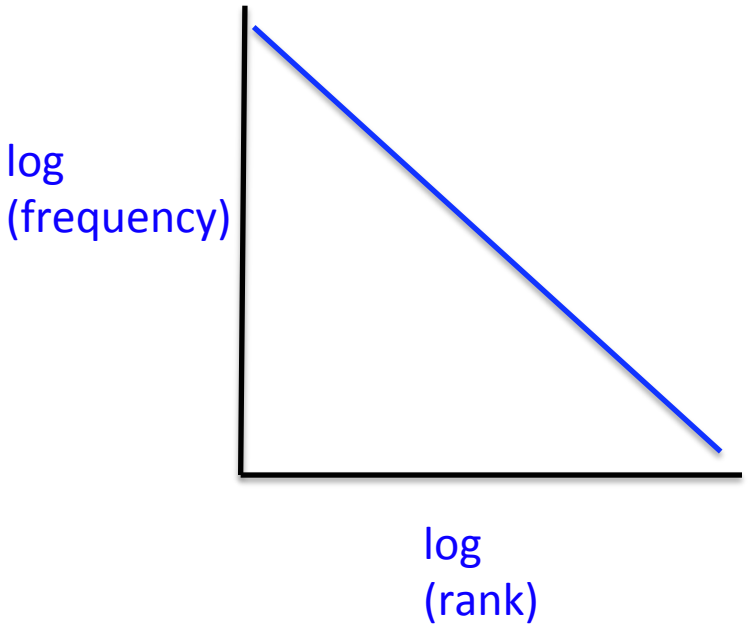

This shows up as a linear relationship in logarithmic space.

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

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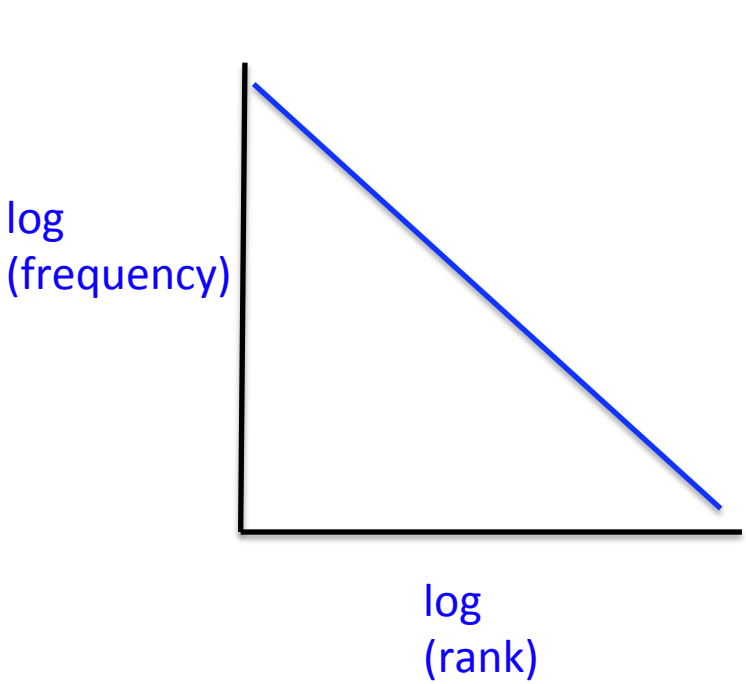
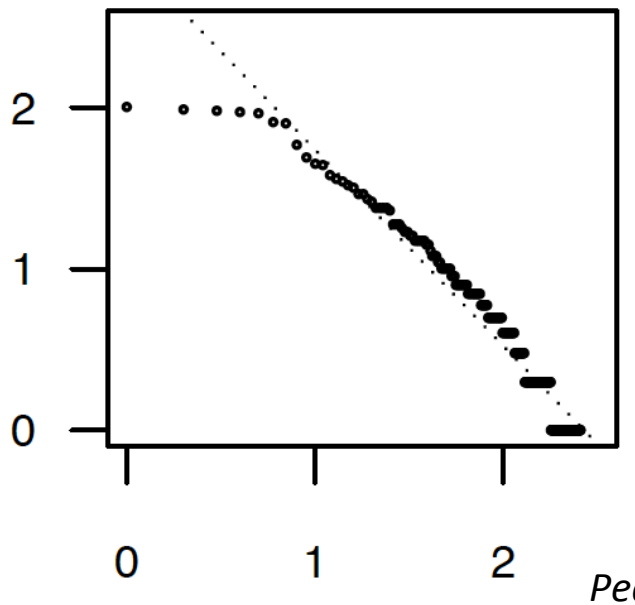
Laura's verb production data during 20-24 months show this power-law distribution.



Laura's verb usage 20-24 months



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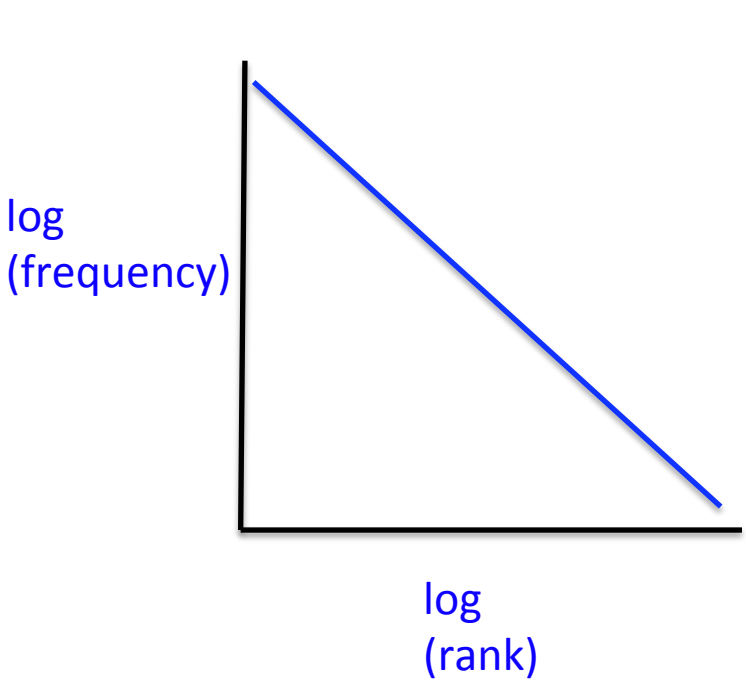
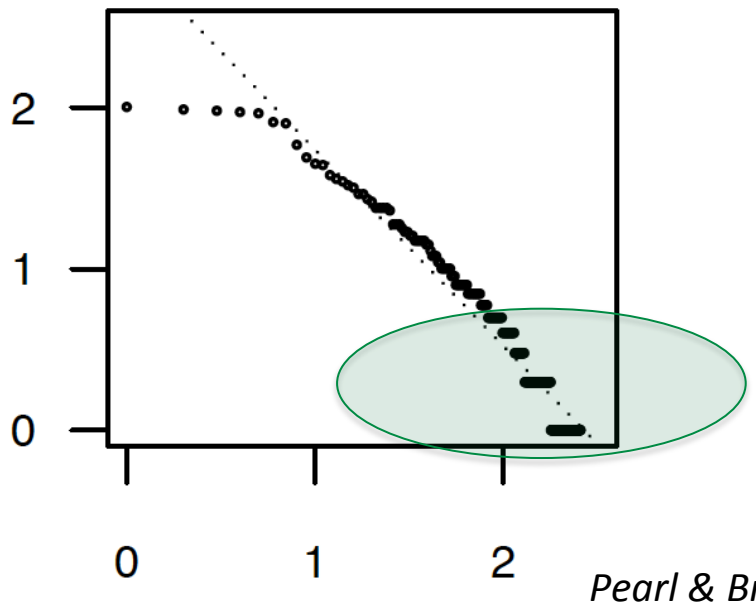
How much overlap do we expect to see if this child knows the category Verb?

One implication: We can't expect much overlap in combinatorial usage for verbs that only are used a few times (and certainly not for those that are only used once).



Laura's verb usage 20-24 months

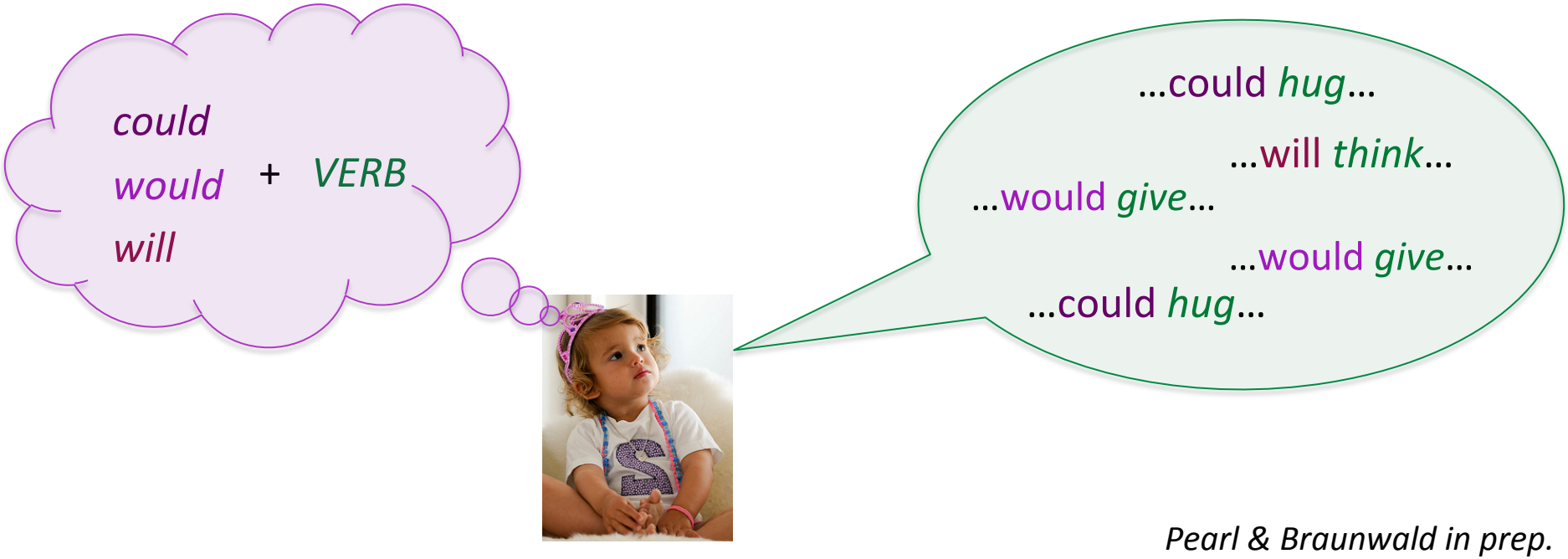


Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

We need to somehow factor in that Laura may have known the combinatorial usage transferred to other verbs, but just didn't choose to say those other verbs with other words.



Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

A way to do this: quantitative methods from Yang 2010, 2011

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

where this is equivalent to this

$$O(r,N,D,S)=1+(D-1)(1-p_r)^S-\sum_{i=1}^{D}\left[(d_i p_r+1-p_r)^S\right]$$

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

A way to do this: quantitative methods from Yang 2010, 2011

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

{hug, give, take, read, want, think, …} = ???

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

A way to do this: quantitative methods from Yang 2010, 2011

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

The probability that a particular verb with rank *r* will have overlap…

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

verb	freq	rank
get	101	1
go	100	2
…		
feel	8	58
…		
dream	1	251
…		

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

A way to do this: quantitative methods from Yang 2010, 2011

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

…given the total number of verb vocabulary items N combining with the lexical items from the class of interest…

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

verb (used with auxiliary) total = 59
like
go
…
cook
…
make
…

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

A way to do this: quantitative methods from Yang 2010, 2011

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

…and the number of combinatorial vocabulary items from the lexical class of interest *D*…

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

auxiliary total = 25
don't
can't
…
do
…
are
…

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

How much overlap do we expect to see if this child knows the category Verb?

A way to do this: quantitative methods from Yang 2010, 2011

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

…and the number of verb usages observed with the combinatorial vocabulary items of interest *S*.

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

auxiliary + verb usage total = 220
don't close the door
can't reach it
…
do not come
…
are you cooking that?
…

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

Once we know this expected overlap, we can look at the overlap we actually observe in the empirical data and see if they match.

Expected overlap

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

Estimate of empirical overlap:

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

Once we know this expected overlap, we can look at the overlap we actually observe in the empirical data and see if they match.

Expected overlap

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

Estimate of empirical overlap:
If verb is used with more than one lexical item within the lexical class (ex: auxiliaries), overlap for that verb = 1.

…could give…
…would give…
…could give…
…could give…

overlap for *give* = 1

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

Once we know this expected overlap, we can look at the overlap we actually observe in the empirical data and see if they match.

Expected overlap

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

The proportion of observed verbs that should have some overlap:
0.0 - 1.0

Estimate of empirical overlap:
If verb is used with more than one lexical item within the lexical class (ex: auxiliaries), overlap for that verb = 1. Otherwise, overlap = 0.

…could give…
…could give…
…could give…
…could give…

overlap for *give* = 0

Pearl & Braunwald in prep.

Assessing knowledge of grammatical categories

Once we know this expected overlap, we can look at the overlap we actually observe in the empirical data and see if they match.

Expected overlap

$$O(D,N,S)=\frac{1}{N}\sum_{r=1}^{N}O(r,N,D,S)$$

The proportion of observed verbs that should have some overlap: 0.0 - 1.0

Estimate of empirical overlap:
If verb is used with more than one lexical item within the lexical class (ex: auxiliaries), overlap for that verb = 1. Otherwise, overlap = 0.

If expected and empirical overlap match, this child's output is compatible with knowing the grammatical category Verb.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Investigate a number of different lexical classes that can combine with verbs – each one is an individual assessment of productivity, which can be viewed collectively to assess whether the category Verb is known.

Expected overlap
Empirical overlap
Exp - Emp

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Comparing expected to empirical overlap for 7 classes of lexical items, it doesn't seem like verbs combine freely with words from different lexical classes.

Knowledge is not transferring across different verbs.

	subj	obj	non-obj	neg	aux	wh	emb cla
Expected overlap	0.70	0.75	0.63	0.45	**0.51**	0.54	0.69
Empirical overlap	0.48	0.50	0.51	0.36	**0.49**	0.25	0.57
Exp - Emp	0.32	0.25	0.12	0.09	**0.02**	0.29	0.12

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

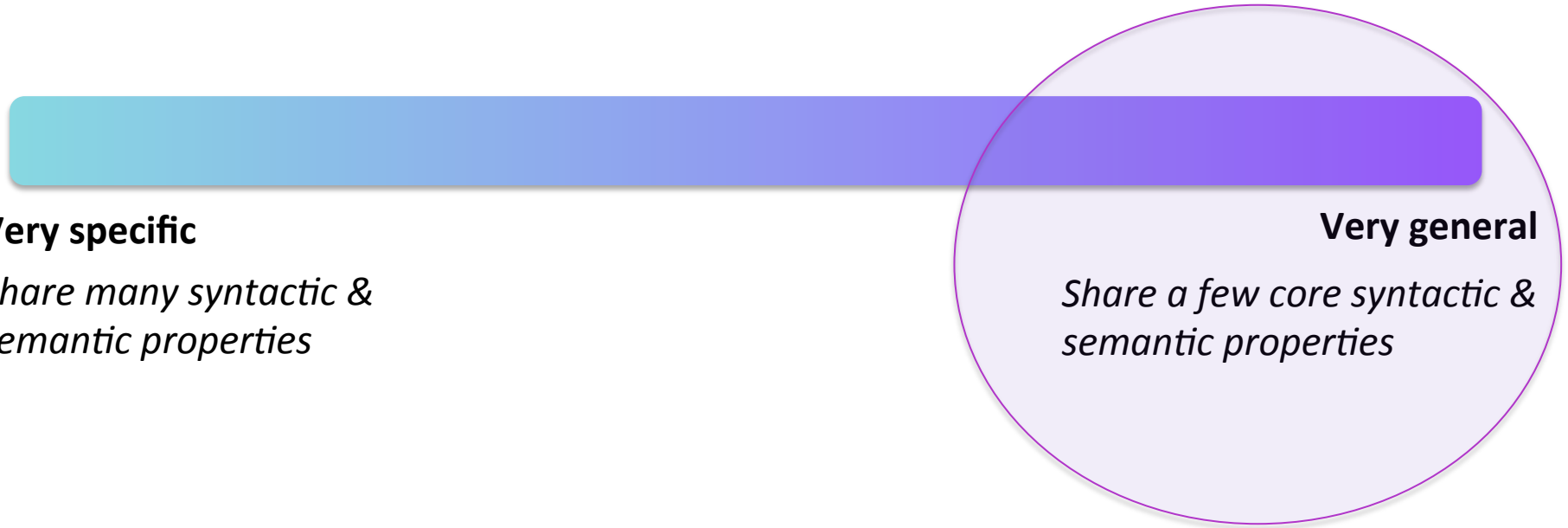
Implication:
Despite the number of verbs the child is producing (260 verb vocabulary items), development of grammatical category knowledge (Verb) does not occur until after this age.

Pearl & Braunwald in prep.

Assessing the development of knowledge about language

One example of using computational methods to assess the development of language knowledge, given naturalistic data.

When does this knowledge typically develop?



Very specific

Share many syntactic & semantic properties

Very general

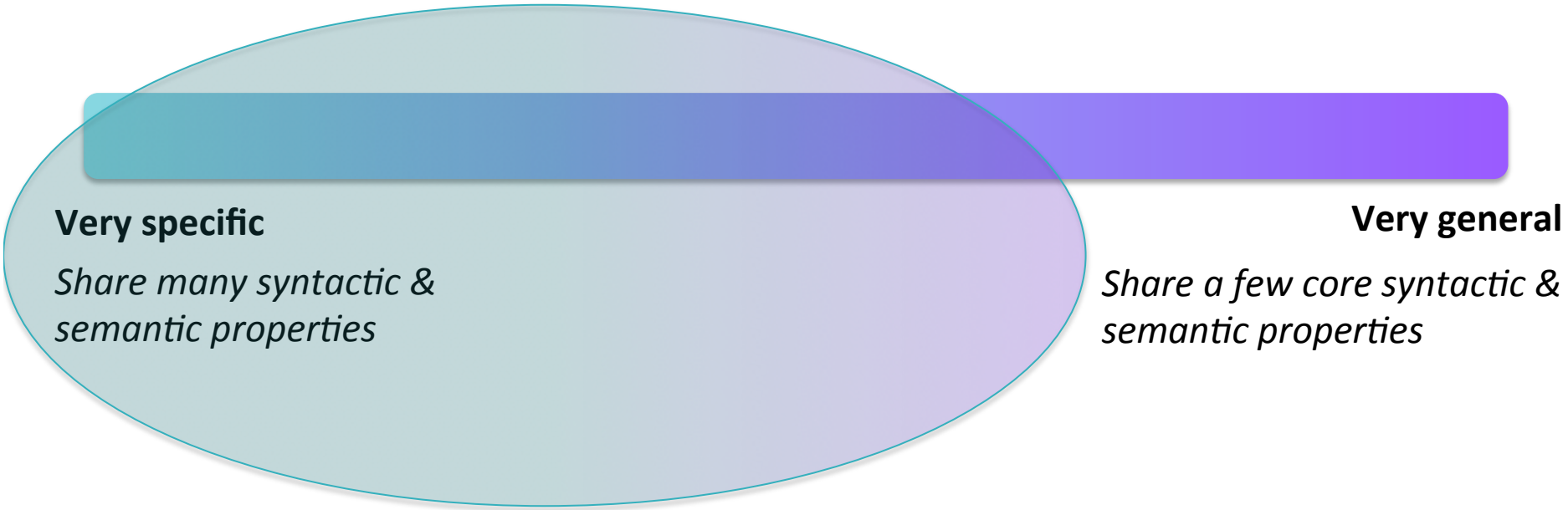
Share a few core syntactic & semantic properties

This takes some time to develop, even when children already have a significant vocabulary.

Pearl & Braunwald in prep.

Assessing the development of knowledge about language

When does more specific knowledge about abstract categories in language typically develop?



Verbs of communication
whisper, shout, say, mumble, tell, …

Assessing the development of knowledge about language

More generally: Determine the typical age of development for different kinds of abstract knowledge that can aid vocabulary acquisition

That **feline** is playing with the dog again.

That ____ is playing

related to *dog*

Animate Noun

animate entity

Guess:
Other animal that can be a pet?

Assessing the development of knowledge about language

Assess whether children are typical or atypical in their categorical knowledge, given their naturalistic output, such as writing samples. (Can avoid test anxiety.)

Does this child group together verbs of communication?
How often are these used with animate subjects, language objects (ex: “word”, “name”), and indirect objects?

whisper, shout, say, mumble, tell, …

Helping children learn

Delayed learners: Help design individualized intervention methods based on a delayed individual's specific vocabulary category deficits.

Typical & delayed learners: Help design educational methods for introducing new vocabulary & aiding in reading comprehension

Hermione *whispered* the name to Harry.
Harry *shouted* the name back to her.
Dumbledore *announced* a warning for them both.

Linguistic features associated with verbs of communication:
animate subject, language object, indirect object

Today's Plan

Using computational methods to look at one question about children's learning and discussing connections to education

When do children learn different aspects of knowledge?

Assessing individual abilities:
When does the child attain a certain level of knowledge?
Connections: literacy development

Identifying factors that underlie the observable output:
What signifies atypical development, which may require intervention?
Connections: math readiness

numerical cognition

5

Language & Math

Spoken language knowledge: a prerequisite for math

Language knowledge is required to create new concepts, such as exact numbers.

1, 2, 3, 4, 5, 6….

counting list

5

6

Numerical cognition

Knowledge of cardinal numbers is a fundamental building block for more sophisticated math concepts

- precursor for successful acquisition of mathematical knowledge:
  a signal of "math readiness"
- knowledge at kindergarten can predict later math achievement through at least the 5th grade (Ginsburg & Russell 1981, Duncan et al. 2007)

5

6

5+6 = 11

*6*5 = 30*

…

Cardinal number knowledge

There's wide variation in cardinal number knowledge in kindergarteners.

It's unclear what factors contribute to this observable variation (nature vs. nurture) and how much each factor contributes.

Pearl & Sarnecka

Development of cardinal number knowledge

It takes a while for children to realize what the counting list maps to.

Sophisticated numerical knowledge = **Cardinal Principle**

The last number reached when counting the items in a set represents the entire set.

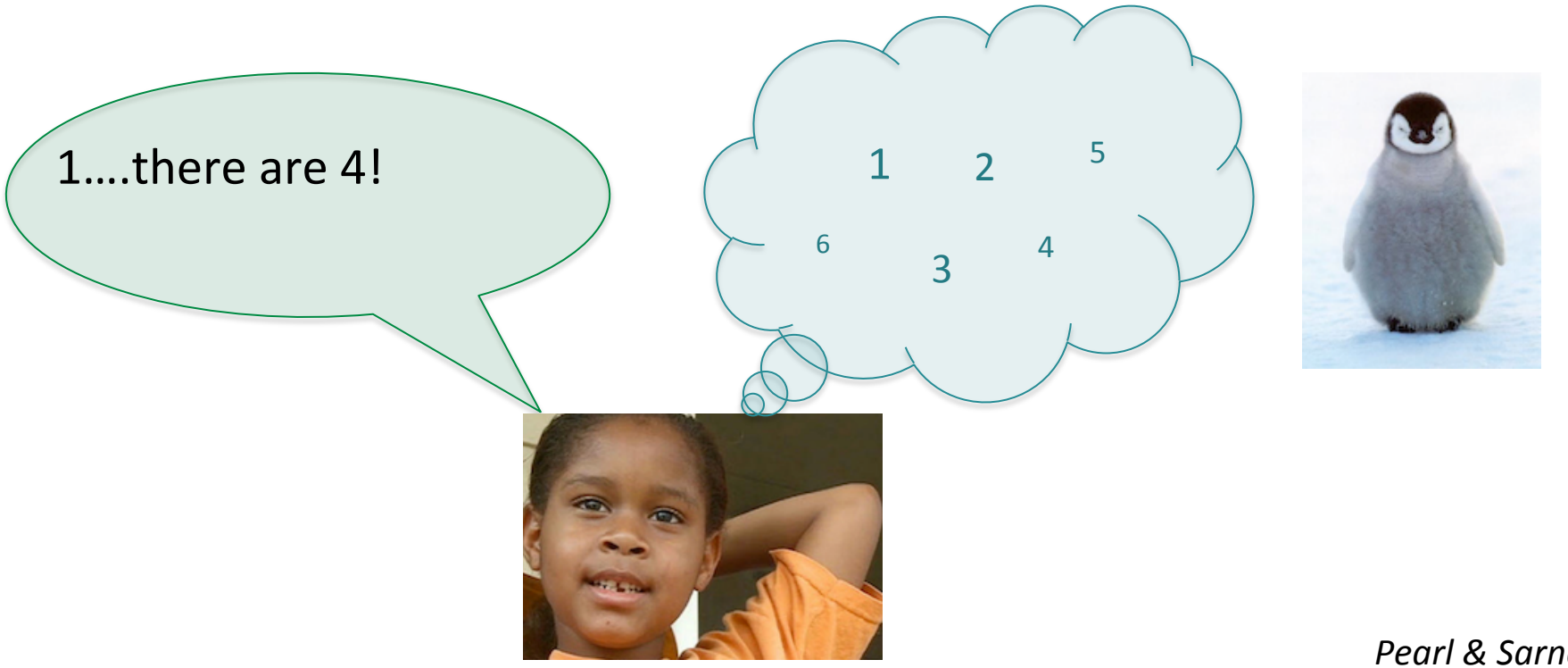
1, 2, 3, 4, 5, 6….there are 6!

Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

Pre-number knowers haven't mapped any of the counting list.



Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

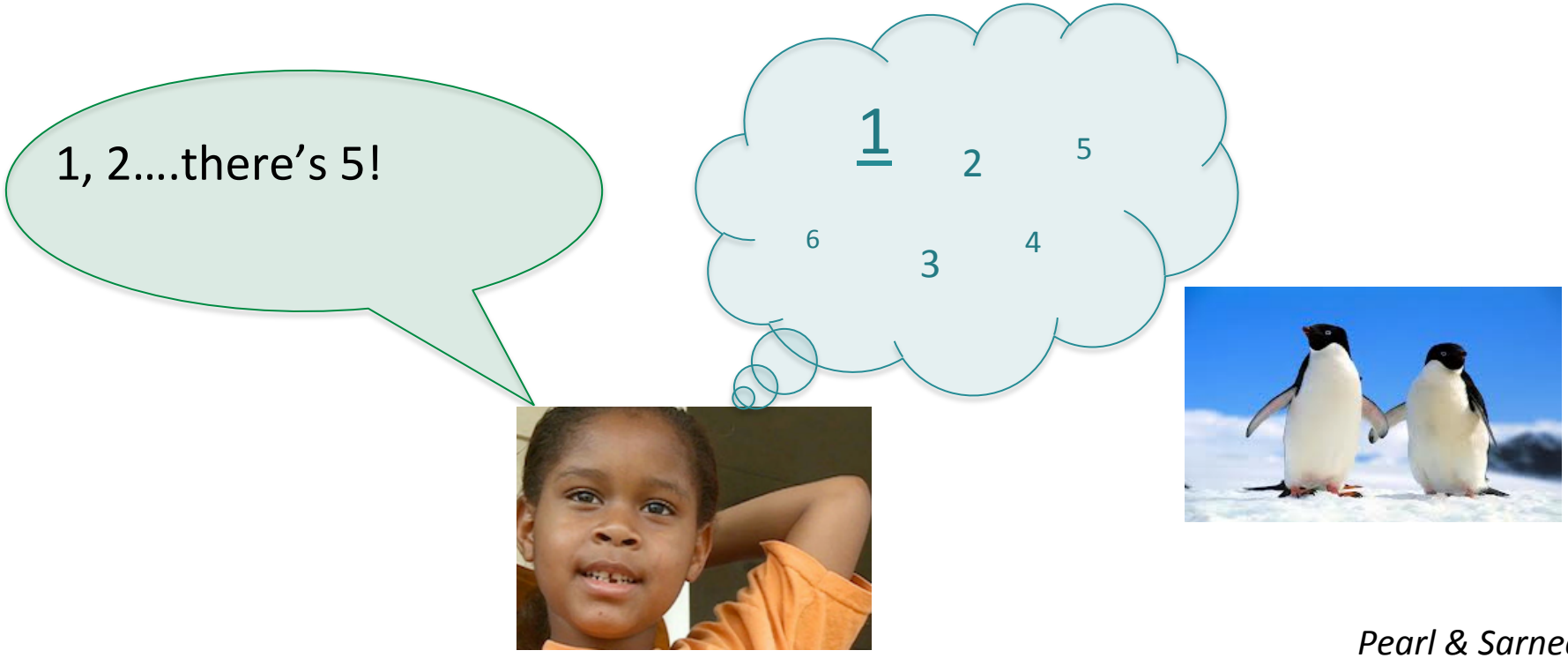
One-knowers have only mapped 1.

Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

One-knowers have only mapped 1.

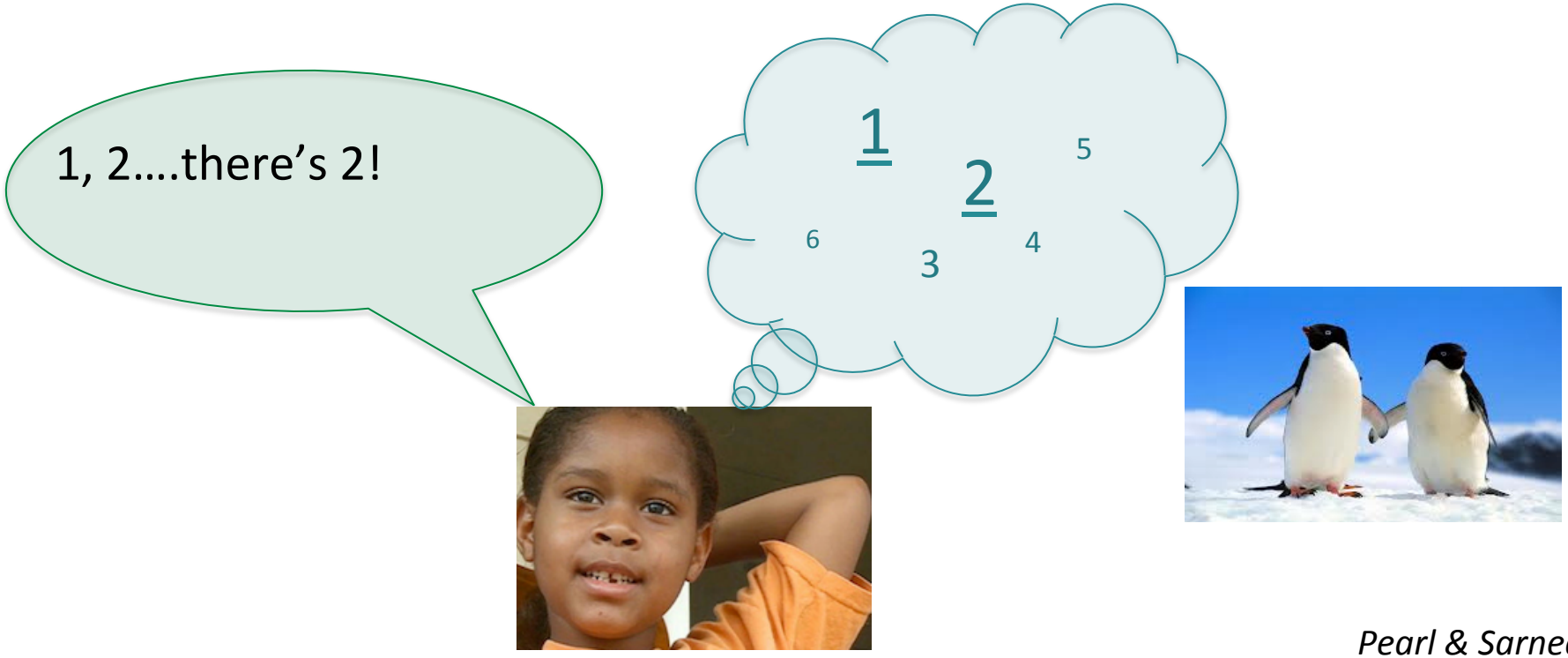


Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

Two-knowers have only mapped 1 and 2.



Pearl & Sarnecka

Development of cardinal number knowledge

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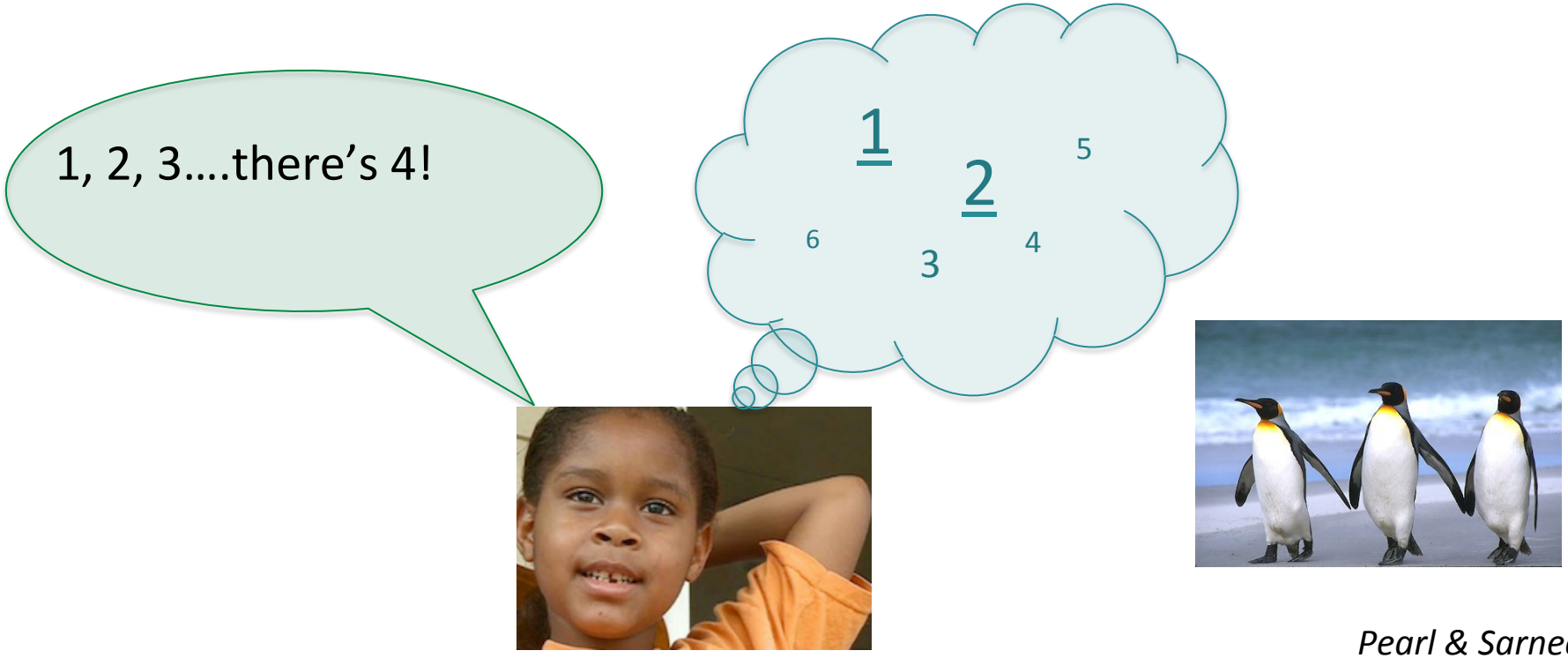
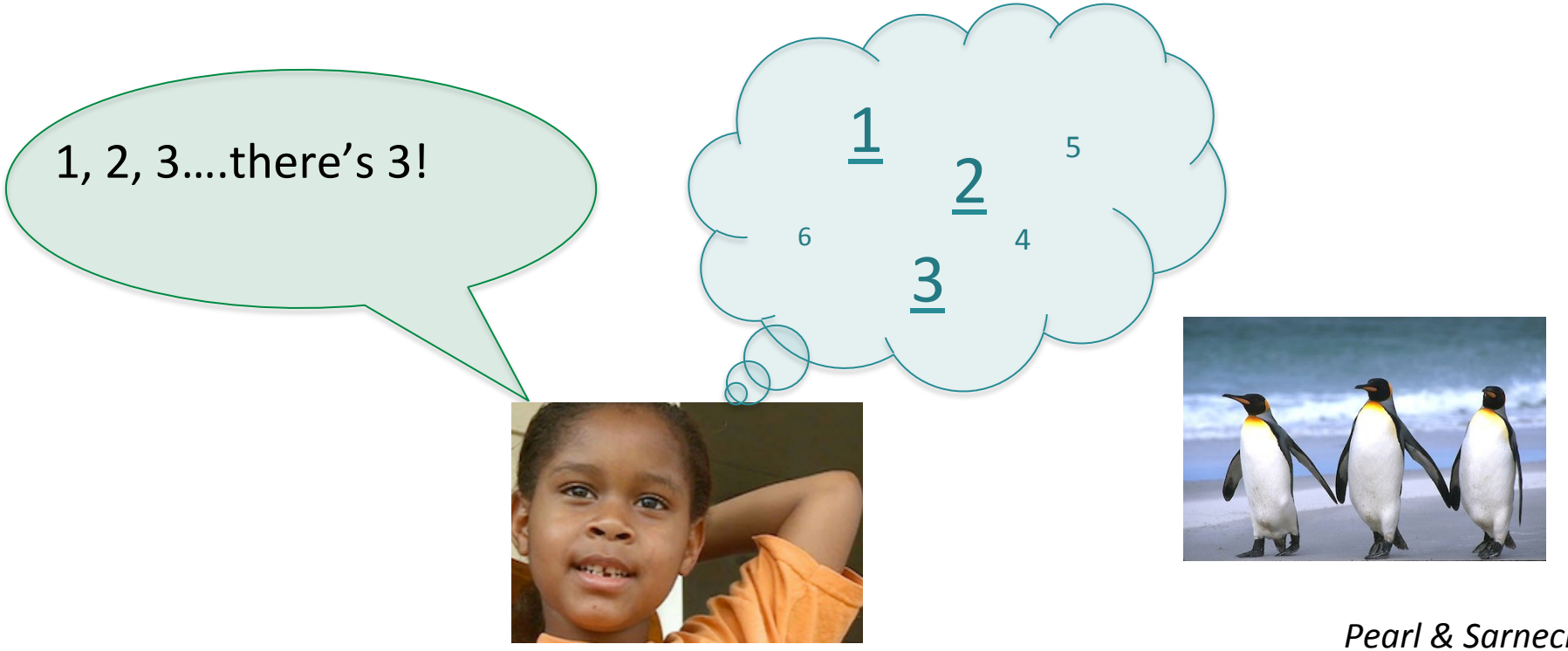


Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

Three-knowers have only mapped 1, 2, and 3.

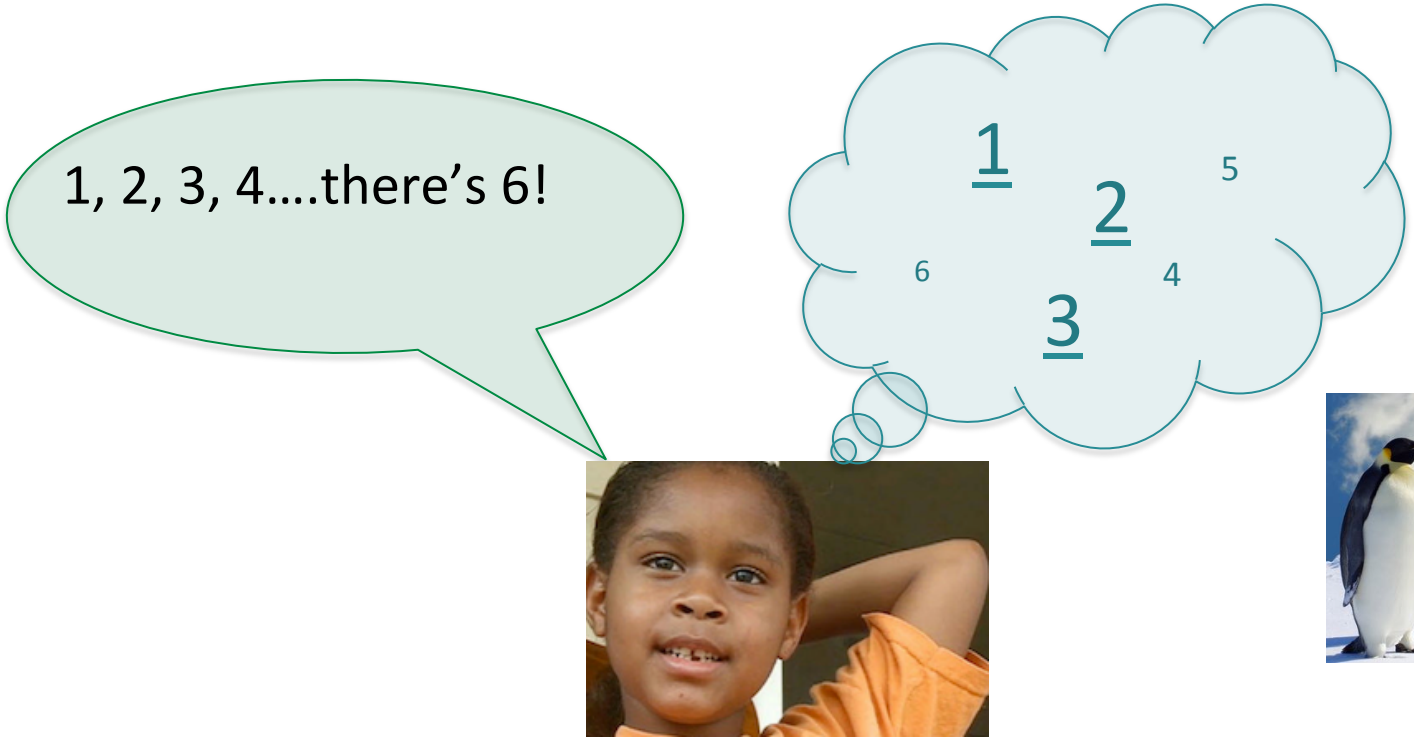


Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

Three-knowers have only mapped 1, 2, and 3.

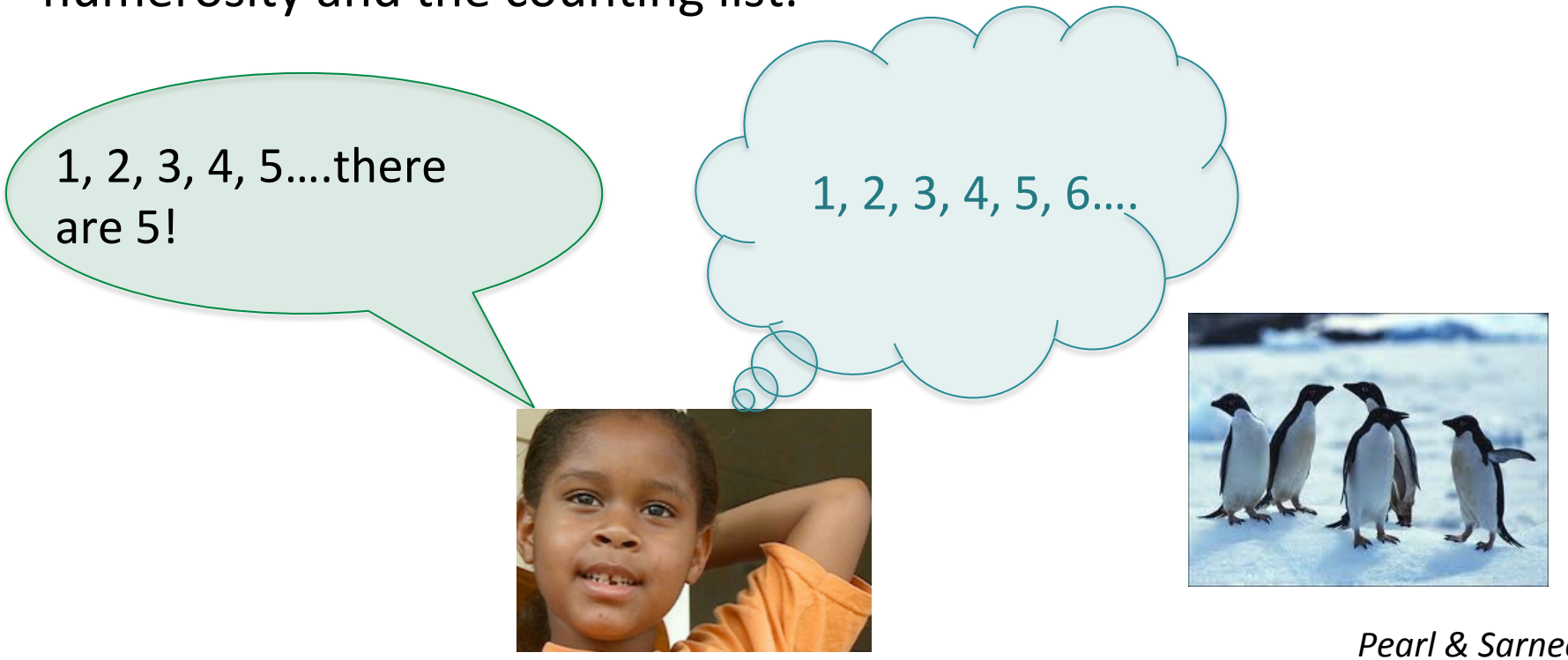


Pearl & Sarnecka

Development of cardinal number knowledge

Children progress through different levels of knowledge on their way to discovering the Cardinal Principle (Wynn 1992, Sarnecka & Carey 2008, Sarnecka & Lee 2009).

Cardinal Principle (CP) knowers realize the mapping between numerosity and the counting list.



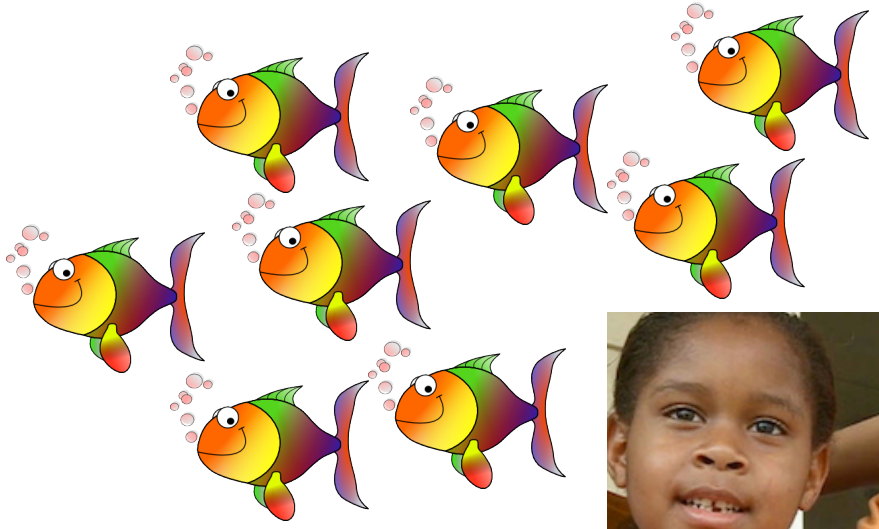
Pearl & Sarnecka

Development of cardinal number knowledge

We can gauge which stage children are at using experimental methods.

Give-N Task (Wynn 1992):

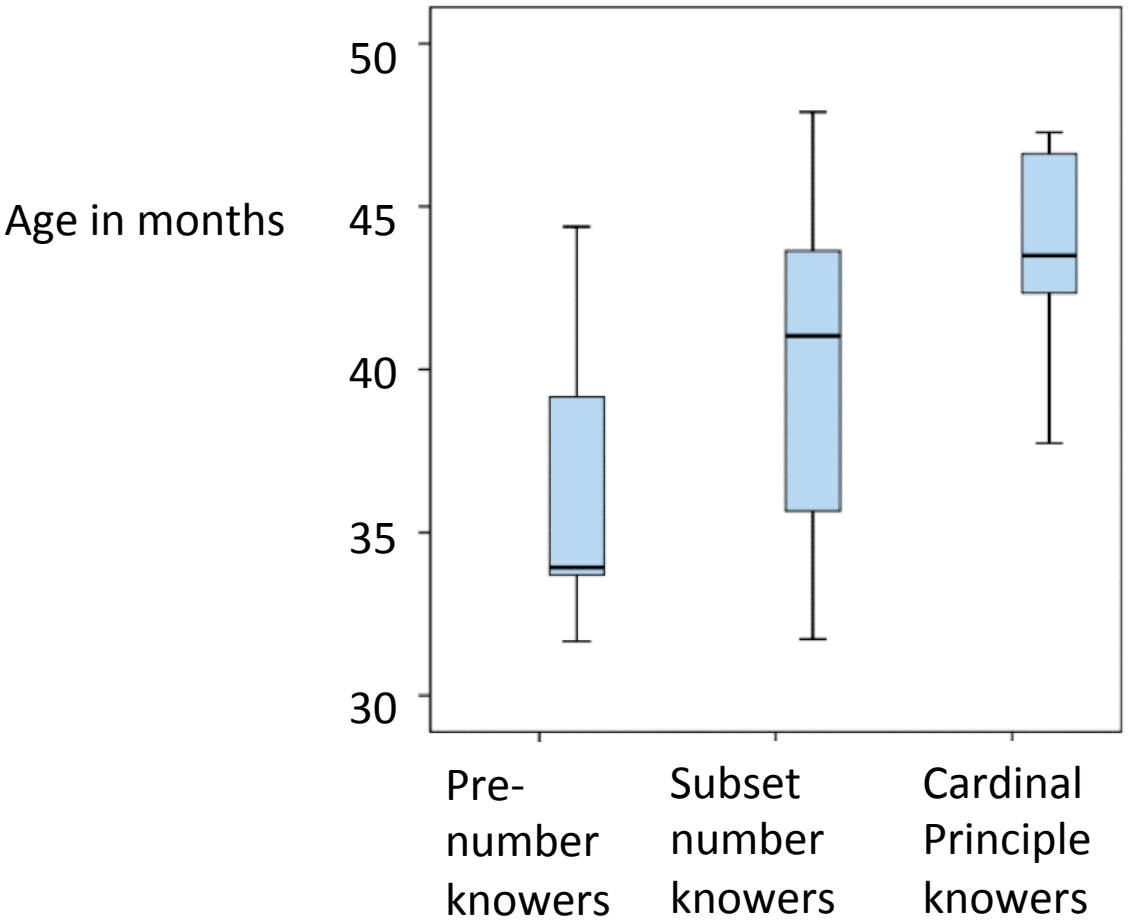
"The way we play this game is: I will tell you what to put on the plate, and you put it there and sli-i-i-de it over to Kitty, like this [demonstrating]. OK, can you give one fish to Kitty?"



Pearl & Sarnecka

Development of cardinal number knowledge

We can then get a sense of when children typically pass through the different number-knower stages.



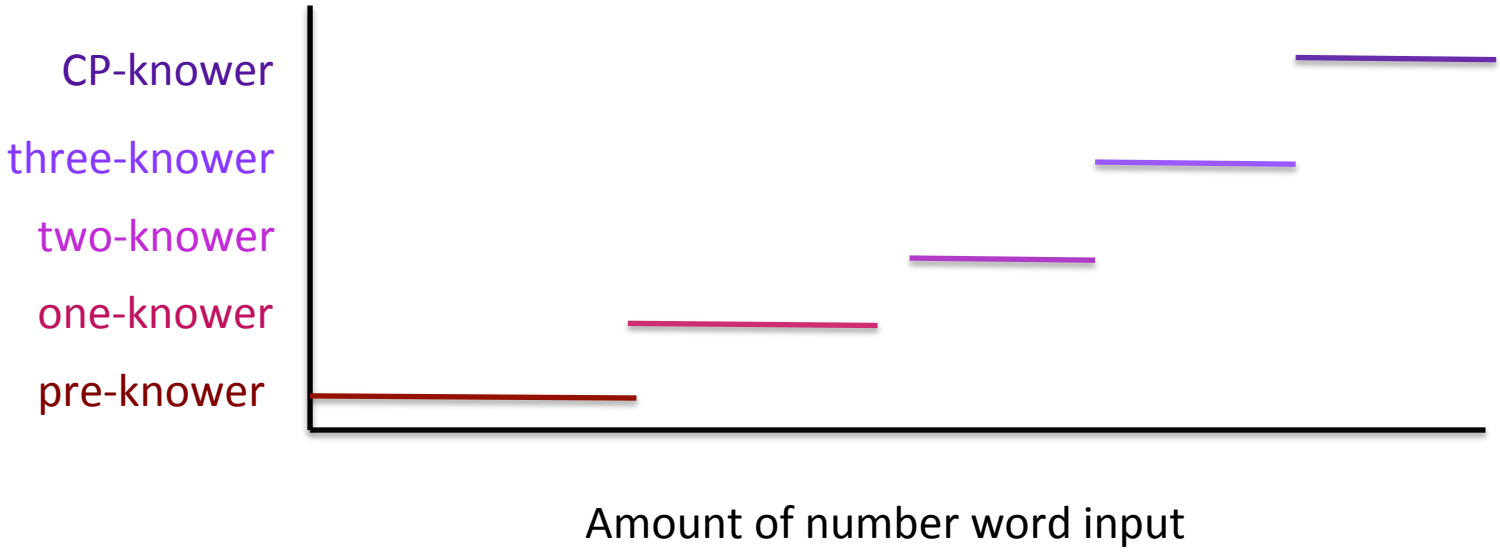
Slusser 2010:
Monolingual,
High SES children

Pearl & Sarnecka

Development of cardinal number knowledge

Training study in progress (Barbara Sarnecka): Collecting longitudinal data on children from different language (monolingual vs. bilingual) and SES (high vs. low) backgrounds to determine typical "time to cardinality", as measured by the amount of number word input they receive.

For each child, we can get something like this:



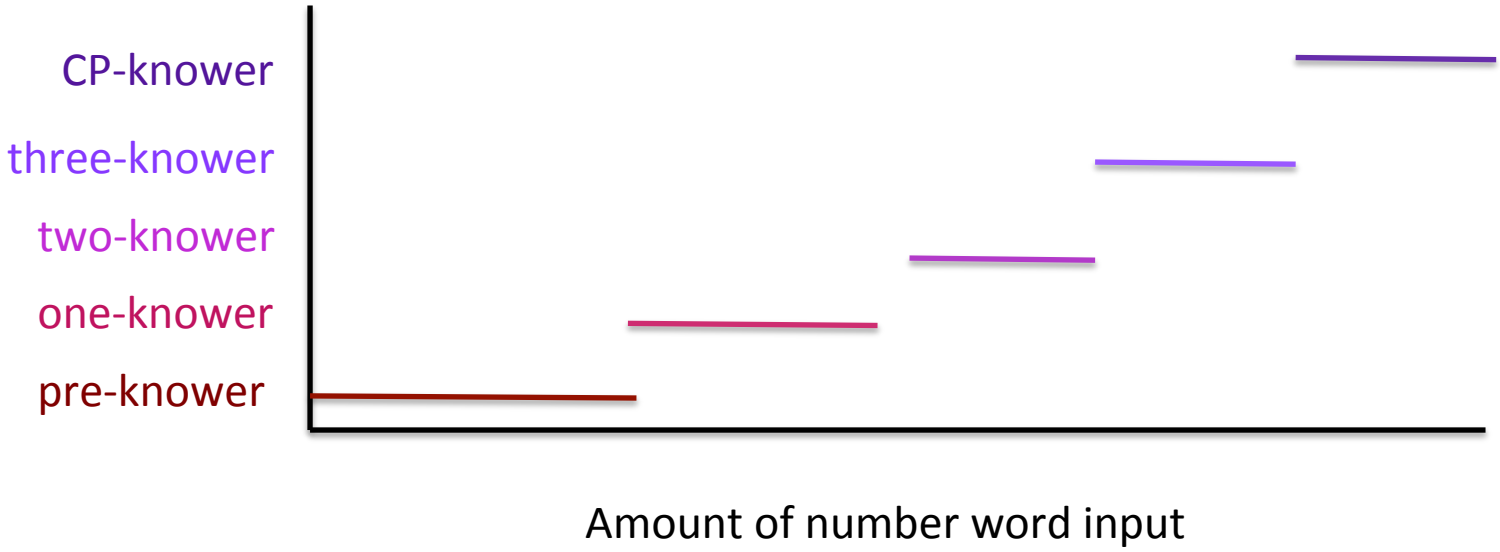
Pearl & Sarnecka

Understanding the development of cardinal number knowledge

We can then investigate the factors that underlie this progression.

- One known external factor: input quantity (Levine et al. 2010, Gunderson & Levine 2011)
- Other potential internal factors: creativity, conceptual capacity, conservativity

For each child, we can get something like this:

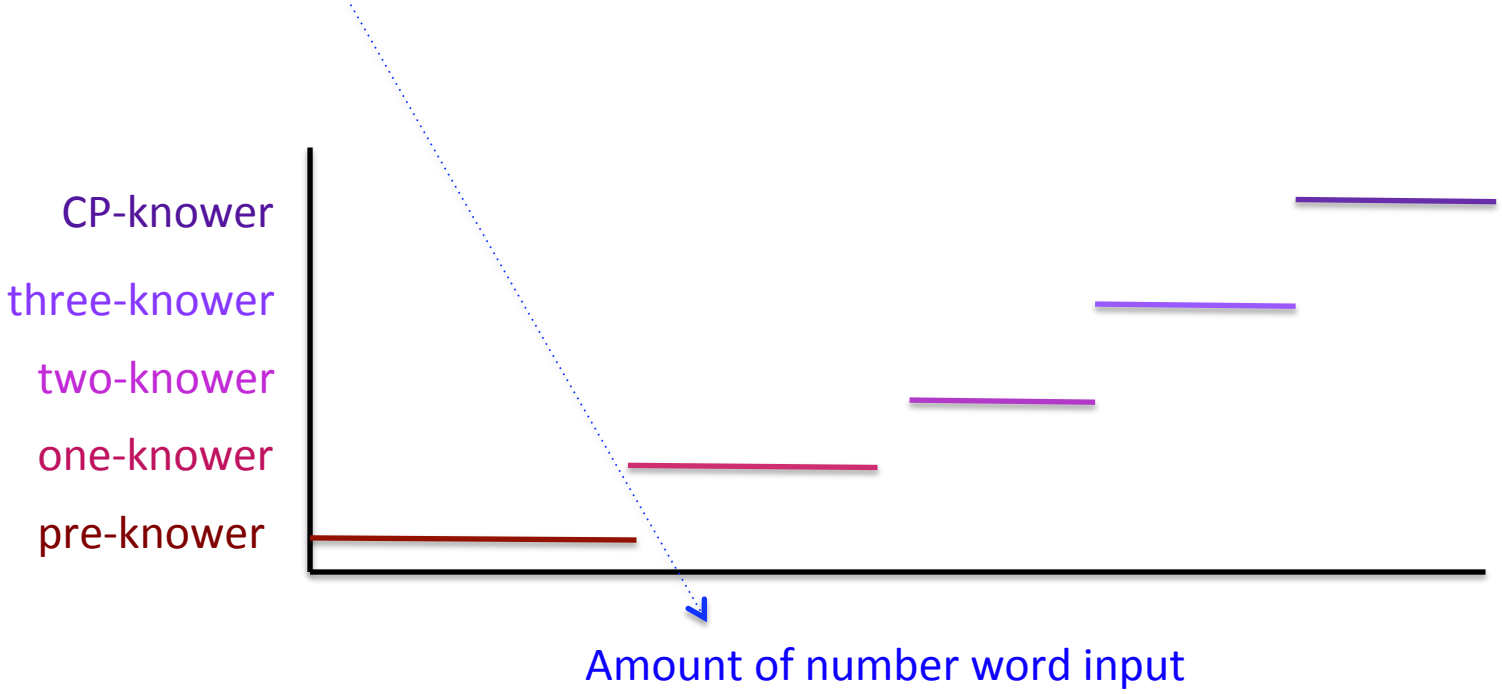


Pearl & Sarnecka

Understanding the development of cardinal number knowledge

We can create a cognitive process model (Yang 2002, Pearl 2011) that can reproduce this trajectory, and that depends on all these factors.

Input quantity (I): how much data the child has encountered (observed, external variable)

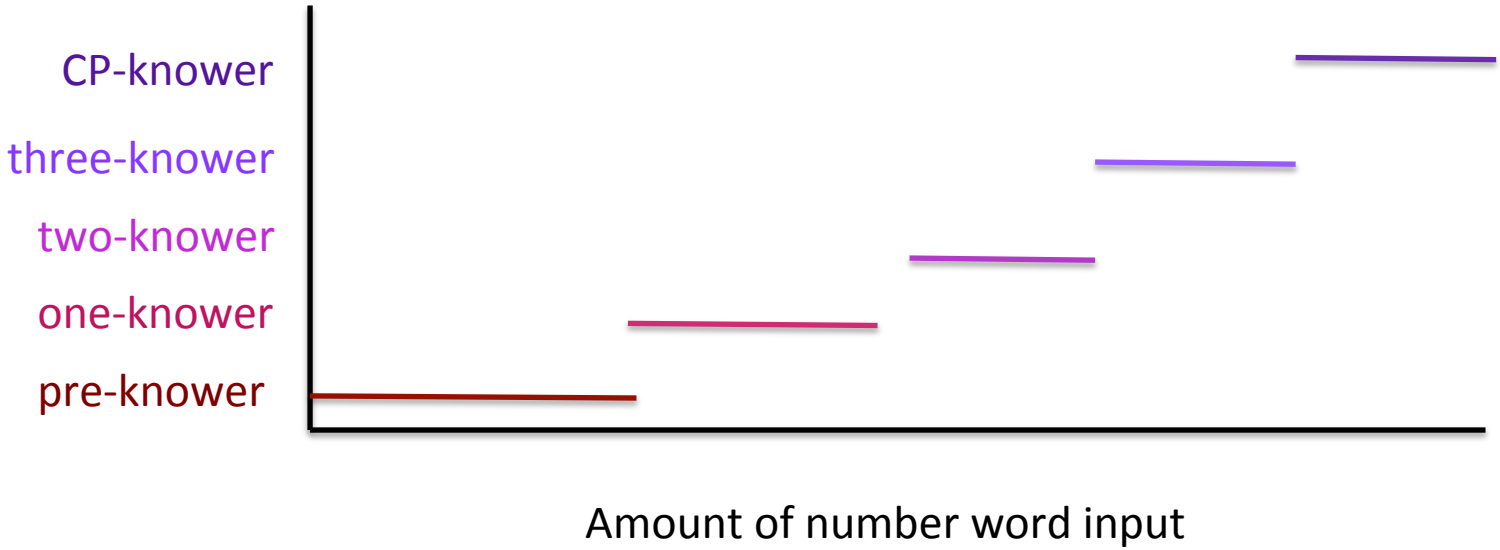


Pearl & Sarnecka

Understanding the development of cardinal number knowledge

We can create a cognitive process model (Yang 2002, Pearl 2011) that can reproduce this trajectory, and that depends on all these factors.

Creativity (α): how likely the child is to consider a new hypothesis about the meaning of number words

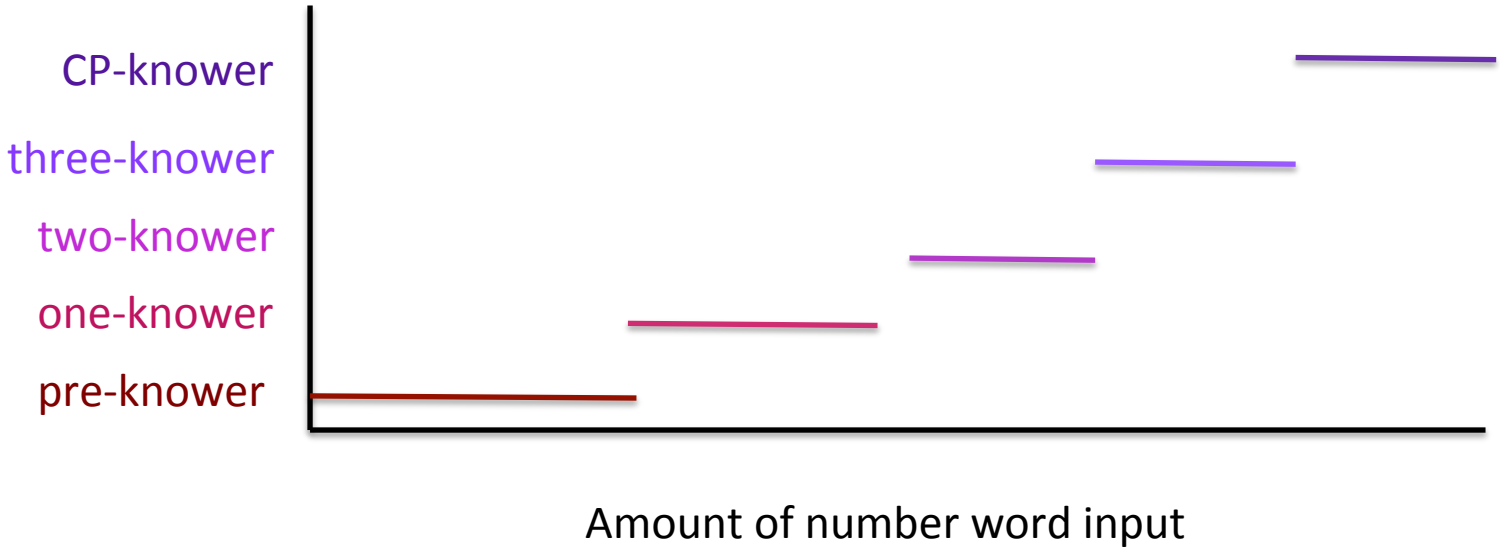


Pearl & Sarnecka

Understanding the development of cardinal number knowledge

We can create a cognitive process model (Yang 2002, Pearl 2011) that can reproduce this trajectory, and that depends on all these factors.

Conceptual capacity (β): how difficult it is for the child to imagine rules like the Cardinal Principle

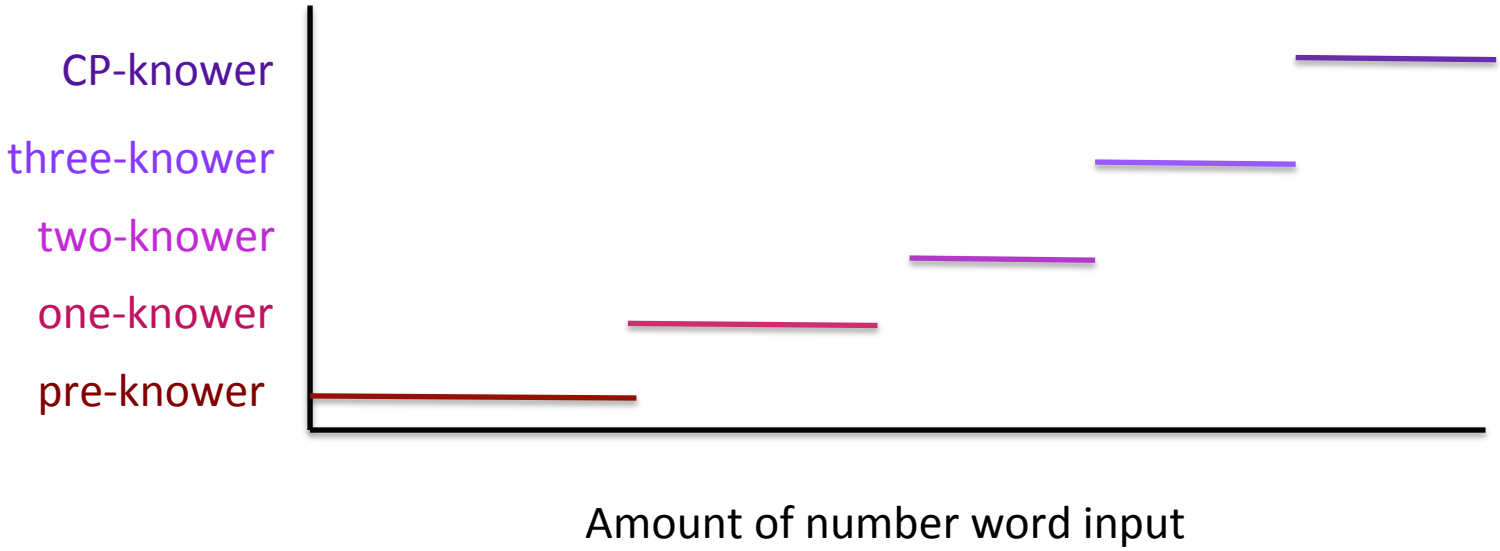


Pearl & Sarnecka

Understanding the development of cardinal number knowledge

We can create a cognitive process model (Yang 2002, Pearl 2011) that can reproduce this trajectory, and that depends on all these factors.

Conservativity (γ): how much a child's belief in what number words mean shifts on the basis of a single data point



Pearl & Sarnecka

Understanding the development of cardinal number knowledge

Once we have these values for a large sample of children, we can determine what the range for typical development is.

I = 200
α = 0.7
β = 0.2
γ = 0.01

I = 180
α = 0.8
β = 0.22
γ = 0.03

I = 220
α = 0.6
β = 0.25
γ = 0.02

I = 260
α = 0.65
β = 0.15
γ = 0.01

Pearl & Sarnecka

Understanding the development of cardinal number knowledge

We can identify the values outside the norm associated with delayed learners, and for any given child, which factors seem to be causing the delay.

I = 300
α = 0.4
β = 0.20
γ = 0.01

I = 375
α = 0.65
β = 0.05
γ = 0.002

Pearl & Sarnecka

Helping children learn

This can then help identify children who are at risk for later math difficulty, and help design targeted interventions for them.

I = 300
α = 0.4
β = 0.20
γ = 0.01

I = 375
α = 0.65
β = 0.05
γ = 0.002

Pearl & Sarnecka

Recap

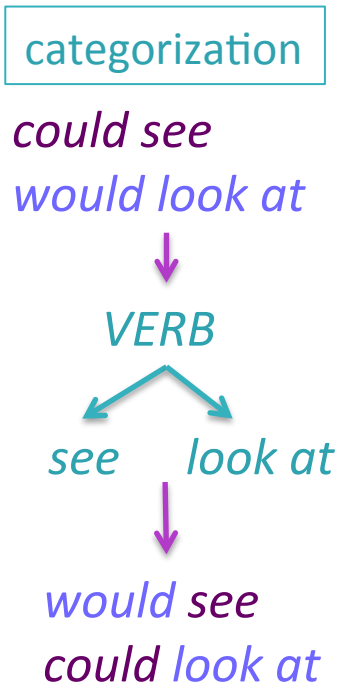
Using computational methods to identify when children learn different types of knowledge

Assessing individual abilities:
When is knowledge attained?

One finding: Basic grammatical category information develops later than two in a typically developing child.

Extensions: When do other linguistic categories develop that are useful for vocabulary acquisition and reading comprehension?

Connections: literacy development



Recap

Using computational methods to identify when children learn different types of knowledge

Identifying factors that underlie the observable output:
What causes typical and atypical development?

One application: Identifying internal and external factors underlying the development of cardinal number knowledge, which predicts later math achievement.

Connections: math education

numerical cognition

5

Big picture:
Understanding learning using computational methods

Computational methods are part of an arsenal of empirical investigation methods that we can use to help us understand the process of learning. This includes the learning strategies children use, the learning biases children have, the knowledge representations that are easily learnable, and the time course & causes of knowledge development.

Computational methods

Theoretical methods

Experimental methods

Even bigger picture:
Using insights from some learners to help others

Cognitive Science + Education: If we understand how learning proceeds in typically developing children who have enriched learning environments, we can design targeted, effective early childhood interventions that can recreate this learning experience for other children who are delayed in their knowledge development.

Thank you!

Sue Braunwald

Joseph Nunn

Barbara Sarnecka

Tricia Ignacio

Computation of Language Laboratory

UC Irvine

Extra material

Grammatical category of Verb at 20-24 months?

Investigate a number of different lexical classes that can combine with verbs – each one is an individual assessment of productivity, which can be viewed collectively to assess whether the category Verb is known.

Expected overlap	
Empirical overlap	
Exp - Emp	

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical items used as subjects?

I, you, he, Laura, Daddy, …

Rule ≈ Subject + Verb

	subj
Expected overlap	0.70
Empirical overlap	0.48
Exp - Emp	0.32

It doesn't seem like it.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical items used as direct objects?

me, you, him, Laura, Daddy, …

Rule ≈ Verb + Object

	subj	obj
Expected overlap	0.70	0.75
Empirical overlap	0.48	0.50
Exp - Emp	0.32	0.25

It doesn't seem like it.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical items used as indirect objects, locatives, preposition phrases, or predicate adjectives?

me, there, to the store, pretty, …

Rule ≈ Verb + Non-Object

	subj	obj	non-obj
Expected overlap	0.70	0.75	0.63
Empirical overlap	0.48	0.50	0.51
Exp - Emp	0.32	0.25	0.12

It doesn't seem like it.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical items used as negations?

not, n't, no, …

Rule ≈ Negation + Verb

	subj	obj	non-obj	neg
Expected overlap	0.70	0.75	0.63	0.45
Empirical overlap	0.48	0.50	0.51	0.36
Exp - Emp	0.32	0.25	0.12	0.09

It doesn't seem like it.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical items used as auxiliaries?

could, should, do, can, ….

Rule ≈ Auxiliary + Verb

	subj	obj	non-obj	neg	aux
Expected overlap	0.70	0.75	0.63	0.45	**0.51**
Empirical overlap	0.48	0.50	0.51	0.36	**0.49**
Exp - Emp	0.32	0.25	0.12	0.09	**0.02**

Maybe.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical items used as *wh*-words in questions? *who, where, why, …*

Rule ≈ *wh*-word …. + Verb

	subj	obj	non-obj	neg	aux	wh
Expected overlap	0.70	0.75	0.63	0.45	**0.51**	0.54
Empirical overlap	0.48	0.50	0.51	0.36	**0.49**	0.25
Exp - Emp	0.32	0.25	0.12	0.09	**0.02**	0.29

It doesn't seem like it.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

Can verbs combine freely with lexical item sequences used as embedded clauses? *…Eugene doing it, …Susie coming, …*

Rule ≈ Verb + Embedded Clause

	subj	obj	non-obj	neg	aux	wh	emb cla
Expected overlap	0.70	0.75	0.63	0.45	**0.51**	0.54	0.69
Empirical overlap	0.48	0.50	0.51	0.36	**0.49**	0.25	0.57
Exp - Emp	0.32	0.25	0.12	0.09	**0.02**	0.29	0.12

It doesn't seem like it.

Pearl & Braunwald in prep.

Grammatical category of Verb at 20-24 months?

In general?

Comparing expected to empirical overlap for 7 classes of lexical items, it doesn't seem like it.

	subj	obj	non-obj	neg	aux	wh	emb cla
Expected overlap	0.70	0.75	0.63	0.45	**0.51**	0.54	0.69
Empirical overlap	0.48	0.50	0.51	0.36	**0.49**	0.25	0.57
Exp - Emp	0.32	0.25	0.12	0.09	**0.02**	0.29	0.12

Pearl & Braunwald in prep.